Evaluation of a Video Image Analysis system for the prediction of carcass and meat quality in genetic improvement programmes

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Abstract

Video Image Analysis (VIA) is a digital camera based technology that extracts relevant information from images using purpose tailored image processing software. In the present work, the VSS2000 image analysis system from E+V Technology GmbH has been used in a large lamb abattoir to determine the value of carcasses in an objective, consistent and automated way. In this thesis results are reported of several experiments conducted within the framework of two UK-funded projects. The aims of the research were (i) the calibration and validation of the VIA-technique for the evaluation of lamb carcasses under UK abattoir conditions, with the view to scientifically examine the accuracy and precision of information from the VIA systems as the basis for a value-based marketing system, (ii) to investigate the use of VIA measurements (weights of primal meat yields and carcass dimensional measurements) in sheep breeding programmes to improve carcass and meat quality and (iii) to evaluate the potential of this technology to reward increased carcass quality associated with the use of breeding strategies based on the inclusion of a quantitative trait locus (QTL) for improved muscularity.

Accuracy, precision and consistency of The Meat and Livestock Commission (MLC) carcass classification scheme, currently used in UK abattoirs to evaluate carcass quality, was compared against the VIA system in the prediction of various primal joint weights. The results highlighted the advantage of the VIA system being on average 2% more accurate (measured as coefficient of determination: R^2) and 12% more precise (measured as root meat squared error: RMSE) in predicting weight of primal meat yields (leg, chump, loin, breast and shoulder) of the lamb carcasses than the MLC carcass classification scheme.

The genetic analysis of VIA-based predicted primal joint weights showed substantial additive genetic variance, suggesting that their use in sheep breeding programmes could improve carcass quality either by an improvement of conformation or by an increased weight of the most valuable primal cuts, without an increase in fatness. Favourable associations between VIA primal weights and performance traits indicate

that selection based on VIA traits is possible without a negative effect on average daily gain, live weight and cold carcass weight.

Although computer tomography (CT) and dissection found in related studies significant effects of a Texel muscling-QTL (TM-QTL) for increased muscularity in the loin region, in the present study they could not be identified by both, the current industry carcass evaluation system for conformation and fatness and the VIA system. A calibration of the VIA system against CT measurements resulted in improved VIA prediction equations for primal meat yields and also showed a moderate potential to estimate loin muscle traits measured by CT and to detect partially the effect of the TM-QTL on these traits.

The results of the research demonstrated that VIA is a consistent method to measure carcass composition and that it improved the prediction (accuracy and precision) of primal meat yields compared to the present MLC scoring system. The estimated genetic parameters for VIA primal meat yields suggested that selection for increased lean meat yield from lamb carcass measured using VIA can contribute to genetic improvement of carcass quality without increasing carcass fatness. The results suggest that VIA technology installed in abattoirs could provide the means for the development of a value-based marketing system by paying for weights of the most valuable primal cuts measured using VIA.

Declaration

I declare that this thesis is my own composition and that the research described in it is my own work, unless stated otherwise.

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Publications

Refereed publications

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While typing these lines, I cannot avoid comparing the present thesis to a human tower, or a "castell" as we call it in Catalonia, as they need a similar structure, organization, balance and collaboration to be successful. Building "castells" is a Catalonian tradition that goes back two-hundred years and is still present in many celebrations. The three different structural elements of a "castell" can be found in the elaboration of this thesis. The first one is the base, which has to be firm, comprehensive, experienced, but also flexible to any unexpected event. Then comes the trunk, made up of several levels or "floors", each of them providing hope, enthusiasm and inspiration as well as defining the objectives and focus of the "castell". The trunk then provides the support for the final group to climb up the "castell". The last ones to climb to the top are the children of the group, or "colla castellera". One of them, called the "enxaneta", climbs all the way up the "castell" to make up the "top pommel".

I now feel like a metaphorical "enxaneta", climbing up to the top of a "castell" with the support, guidance and love from family, friends, supervisors, colleagues at SAC and everyone who was part of this "castell" and helped me all the way up to finally accomplish this work. I am particularly thankful to Jenny Macfarlane and Nicola Lambe for their enormous help and for sharing their invaluable knowledge with me. I would also like to express my sincere gratitude to Denis Homer (MLC) who helped me in the data collection and made my time in the abattoir much more enjoyable. My special thanks go to Fiona Lang, Beatriz Villanueva, Elly Navajas, Tomasz Krzyzelewski and Alex Clop for their friendship and precious support during my PhD, for making me laugh and for sharing with me unforgettable moments in Scotland. I would also like to thank those colleagues with whom I shared a special time in SAC: Nuria Prieto, Carol-Anne Duthie, Benito Albarran, Emma Baxter, Maria Saura, Will Brindle and Kostas Zaralis. My warmest thanks go to Pauline Gaberel, for spending part of her Christmas holidays reading my thesis and for being part of my unforgettable time in Scotland.

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List of Abbreviations

a	direct additive effect of the animal
A1	back area of the carcass minus legs
A2	back area of the legs
A3	side area of the hind legs
A4	side area of the saddle,
ADG	average daily gain
AHDB	Agriculture and Horticulture Development Board
Adj-R^2	adjusted coefficient of determination
AS	age at slaughter
BH	combined year of birth, sex and farm
BR	breed
BREAST	breast primal meat yield
CCW	cold carcass weight
ce	common environmental (litter) effect.
CHUMP	chump primal meat yield
cm	centimetres
CONF	conformation
CT	computer tomography
CV	coefficient of variation
DA	dam age
DEFRA	Department for Environment, Food and Rural Affairs
Df	degrees of freedom
EBLEX	English Beef and Lamb Executive
EBVs	estimated breeding values
EU	European Union
E,U,R,O,P	conformation grades: excellent, good, average, poor, very poor
FAT	fat class
fat:bone ratio	fat weight / bone weight (whole carcass)
g	grams

GLM	general linear model
GR	grade rule
h	hour
h^2	heritability
HCC	Hybu Cig Cymru
IMF	intramuscular fat
Kg	kilograms
L1	carcass length from legs to shoulders
L2	carcass length from hock to legs
L3	carcass total length from hock to shoulder
L4	carcass half length of tibia to the shoulder
LEG	leg primal meat yield
LMA	*longissimus* muscle area
LMCNI	Livestock and Meat Commission for Northern Ireland
LOIN	loin primal meat yield
LRMV	loin region muscle volume
LRMI	loin region muscularity index
LSMs	least square means
Lumbar length	lumbar spine length
LVS	lamb vision system
m	maternal genetic effect
MAS	marker-assisted selection
MHz	megahertz
MLL	*musculus longissimus lumborum*
MLL-A	area of the *m. longissimus lumborum*
MLL-W	width of the *m. longissimus lumborum*
MLL-D	depth of the *m. longissimus lumborum*
MLL-wt	average weight of the left and right *musculus longissimus lumborum*
MLC-CF	Meat and Livestock Commission's carcass classification scores for conformation and fatness
mm	millimetres

MQ	meat quality
MRI	nuclear magnetic resonance imaging
Muscle:bone ratio	muscle weight / bone weight (whole carcass)
NIR	near infrared spectral reflectance
NZ	New Zealand
OAR 2/18	sheep chromosome 2/18
pe	permanent environmental effect
PLS	partial least square
PRESS	prediction residual sum of squares
QMS	Quality Meat Scotland
QTL	quantitative trait loci
r	repeatability
R^2	coefficient of determination
REML	restricted maximum likelihood
r_g	genetic correlation
RMSE	root mean squared error
RMSECV	root mean squared error of cross-validation
SAC	Scottish Agricultural College
sd	slaughter day
SD	standard deviation
s.e.	standard error
S.E.D	standard error of difference
SHOULDER	shoulder primal meat yield
SMY	saleable meat yield
SW	scanning live weight
T	birth-rearing type
TL	carcass total length
TM-QTL	Texel muscling-quantitative trait loci
ToughA-Loin	loin muscle shear force, Bristol
ToughB-Loin	loin muscle shear force, SAC
ToughA-Leg	leg muscle shear force, Bristol
ToughB-Leg	leg muscle shear force, SAC

UFD	ultrasonic fat depth
UK	United Kingdom
UMD	ultrasonic muscle depth
VBMS	value-based marketing system
VIA	video image analysis
VIA-DM	video image analysis-dimensional measurements
VIA-primals	predicted carcass primal joint cuts using a video image analysis
VSS2000	lamb video image analysis system from E+V Technology GmbH
W1	maximum carcass shoulder width
W2	minimum carcass breast width
W3	maximum carcass breast width
W4	minimum carcass waist width
W5	maximum carcass legs widths
W6	maximum breast width of the carcass side
W7	minimum waist width of the carcass side
W8	maximum legs widths
W5 / TL	carcass compactness
$[W5+W8]^{1/2}$ / L3	leg compactness
2/3D	two/three dimensional

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Chapter 1

General introduction

1.1 Lamb production in the UK

The United Kingdom (UK) sheep industry is the biggest exporter and producer of sheep meat in the European Union (EU) with a production of 325,000 tonnes, contributing 9% of total livestock output (AHDB meat services 2008). Sheep farming is the main source of economic activity in less favoured areas, and it also helps to maintain infrastructure and enhances landscape and biodiversity. However to continue as a major producer and exporter of lamb, it is essential that the economic viability of the sheep industry is improved.

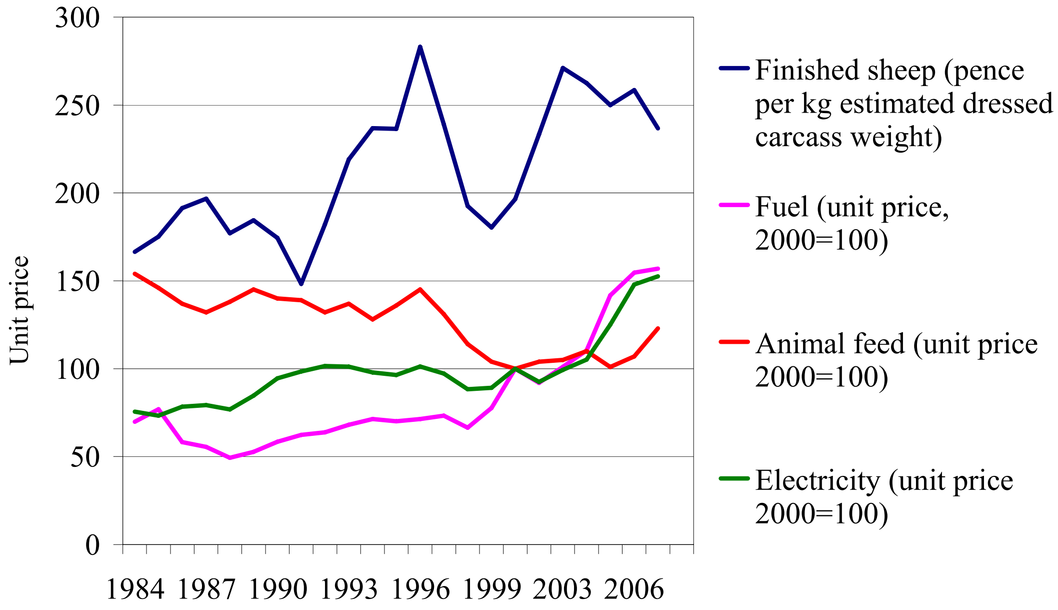

Figure 1.1 Farming costs and lamb price in the UK from 1984 to 2007 (DEFRA 2007)

For years, sheep farming benefited from subsidies linked to the production of sheep and lamb products. However, in 2005, a fundamental change in agricultural policy (Single Farm Payment) was introduced, decoupling subsidy from production and instead rewarding environmentally friendly farming practices. This means that, in order to remain viable, sheep producers in the UK need to be more focused on market returns and enterprise efficiency. This, together with the soaring prices of farming inputs such as fuels, animal feeds, electricity etc. (Figure 1.1), is strengthening relationships between the sheep industry and research community to drive the sheep sector to greater efficiency and longer-term sustainability.

1.2 Product quality

The decline of lamb prices in the UK has also been accompanied by a global decrease in lamb consumption over the last few decades, partly influenced by the consumer's appreciation of product quality (Woodward and Wheelock 1990; Macfarlane 2006). There are several components that can contribute to the definition of lamb product quality. From a consumer's perspective, the two main factors which influence the purchase of meat are meat eating quality (65-68%) and price (25-28%) (Russell *et al.* 2005). Indicators of meat eating quality characteristics include low or modest levels of visible fat (Wood 1990) tenderness, juiciness and flavour. The improvement of these characteristics is of major interest to the lamb industry.

Processor and retailers agree that shelf life and meat colour are also important quality traits to monitor, meat colour being an indication of freshness which may influence the consumer's decision (Mancini and Hunt 2005). Lamb product quality also includes characteristics which are defined at carcass level. A comprehensive model of body form which aimed to account for all major variations in the carcass was suggested by Young *et al.* (2001) and contained five main categories: overall size (e.g. bodyweight, frame size), proportions of major tissues (e.g. fat percentage, muscle to bone ratio), distribution and partitioning of tissues (e.g. muscle percentage in high priced cuts, muscle percentage in loin, fat percentage in subcutaneous depot), shape of tissue units (e.g. muscularity) and density of tissues (weight relative to volume, chemical composition). At present, the value of the carcass in the market is affected by two categories: weight and fatness. Additionally, the current carcass classification system also evaluates conformation, which relates to the shape of the overall carcass (Waldron *et al.* 1992; Bibe *et al.* 2002).

This carcass evaluation system aims to encourage the production of leaner carcass while conformation is improved. Therefore it places economic incentives on producers achieving the target carcass specifications for fatness which for the main UK domestic and export markets are fat classes 2 or 3L. In terms of conformation, most markets prefer scores R or higher (Jones *et al.* 2003). However, only ca. 54% of UK lambs meet core target specifications (AHDB meat services 2008) and a large proportion of carcass are over-fat. As a consequence, some abattoir practises include procedures to increase meat quality by trimming subcutaneous fat which is a common practice in British abattoirs. However, although the consumer is willing to pay more for meat cuts with less visible fat, there is a breakpoint where additional costs of controlled fat trimming could be more than the premium achievable by trimming.

The production of a lamb carcass more closely matched to consumer preferences would reduce costs associated with both production and removal of excess fat and provide clear benefits for both producers and processors. Ideally, the value of a lamb carcass would be mainly based on its composition as described by the yield of lean meat, where the meat is distributed in the carcass, as well as, the quality of the meat (including eating quality) and the proportions of fat tissue and bone. Carcass characteristics currently measured in the abattoirs (e.g. weight, conformation and fatness) are poor indicators of meat eating quality attributes (Lambe *et al.* 2008b). As a consequence, lamb produced for market based on these characteristics may not meet consumer requirements. Automatic technologies are available for both *in vivo* and *post mortem* estimation of carcass quality traits of high economic value, which are useful in animal breeding programmes. These technologies might also have the potential to provide information on meat quality and meat eating quality characteristics (Karamichou *et al.* 2006; Lambe *et al.* 2008b) and they would be of great importance for the development of a value based market system (VBMS) to reward producers for real improvement of lamb product quality.

1.3 Evaluation of carcass quality

A number of the technologies available for evaluation of *in vivo* and *post mortem* body and carcass composition are ultrasound technologies, X-ray computer tomography (CT), dual-energy X-ray absorptiometry, nuclear magnetic resonance imaging (MRI), Video Image Analysis (VIA) and 3-dimension (3D) laser scanning. These technologies vary in accuracy, precision, ease of use, cost, speed, mobility, robustness and public acceptance. In the sheep industry, evaluation of body composition has mainly focused on use of ultrasound (McEwan *et al.* 1989; Stanford *et al.* 1995) and CT measures (Jones *et al.* 2002; Macfarlane *et al.* 2006; Kvame and Vangen 2007). In abattoirs, the use of VIA systems for evaluation of carcass composition has been the main focus in several countries for the last decade (Horgan *et al.* 1995; Hopkins 1996; Stanford *et al.* 1998; Hopkins *et al.* 2004)

While the majority of lamb and beef carcasses are still assessed by visual appraisal, some pig carcasses are evaluated using sophisticated technologies such as AutoFOM, installed in some abattoirs for the evaluation of muscle and fat depths as indicators of lean and fat percentage and primal weights from the whole carcass (Brondum *et al.* 1998; Fortin *et al.* 2004). However, intensive research world-wide on automatic technologies to evaluate lamb and beef quality indicates that this situation might also be changing for these species in the near future, with the first imaging techniques to estimate carcass quality having been installed in lamb and beef abattoirs in Australia, New Zealand (NZ), Ireland and the UK.

1.3.1 In vivo evaluation of carcass quality

Ultrasound imaging has become a widely used tool in animal production over the past few decades (McEwan *et al.* 1989; Ward *et al.* 1992; Hopkins *et al.* 1993). Ultrasound scanning has been used in the UK sheep industry to obtain measures of muscle depth, measured vertically at the deepest point of the eye-muscle (*musculus longissimus dorsi)*, and fat depth taken over the *longissimus dorsi* muscle. This technology is mobile, fast and cost-effective for use on a large number of animals and for these reasons it has been widely used in sheep breeding to help in the selection of leaner carcasses. However, ultrasound requires manual measurement of tissue depths and is less effective in discriminating clearly between carcass tissues. It is therefore more susceptible to noise than some other technologies such as CT or MRI (Glasbey *et al.* 1996).

In the 1970s, CT was first introduced in human medicine (Hounsfield 1973). The methodology is based on a non-invasive imaging of subjects which allows cross-sectional images of the body to be obtained *in vivo* (Davies *et al.* 1987). At this early stage, CT was recognized as a potential technique for use in animal production research (Allen and Leymaster 1985). The first results indicated that the technique had considerable potential for predicting carcass composition in live pigs (Allen and Vangen 1984; Vangen and Standal 1984) and sheep (Sehested 1984). Later studies confirmed the accuracy and precision of CT for prediction of body composition (Young *et al.* 2001; Jones *et al.* 2002; Lambe *et al.* 2003; Jopson *et al.* 2004; Macfarlane *et al.* 2006) and suggested its application for the estimation of carcass quality in sheep breeding programmes.

Computer tomography has also recently been used to quantify muscularity in sheep (Jones *et al.* 2002; Navajas *et al.* 2007). Measures of muscularity, which by definition is independent of fatness (Purchas *et al.* 1991), have been suggested as an alternative method to improve carcass conformation, in addition to leanness, using measurements that, at a constant weight, are independent of fatness. The use of CT muscularity measures in selection indexes could improve carcass quality by improving conformation and could also have an effect on the visual appeal and attractiveness of meat cuts for consumers (Laville *et al.* 2004).

In vivo CT measurements of muscle density have also proved to be a promising technique that may enable the selection of live animals for intramuscular fat content, and hence improve meat eating quality, without any detrimental effect on muscularity or muscle weight as measured by CT (Navajas *et al.* 2008). These results supported the findings of Karamichou *et al*. (2006) where favourable correlations were found between CT muscle density measurements and juiciness, flavour and overall palatability of meat from Scottish Blackface lambs.

In a recent study, Kongsro *et al*. (2008), reported that CT measures of fat, lean and bone were more accurate than those measures obtained by manual dissection on lamb carcasses. These results indicate the possibility of using CT technology as a reference method in order to calibrate other carcass evaluation methods such as automated technologies like VIA which require dissection datasets to develop the prediction models.

1.3.2 Post mortem evaluation of carcass quality

One of the most important factors for the success of a VBMS in the UK sheep industry is that the quality attributes of lamb carcasses are accurate and precisely evaluated. Carcass evaluation systems must serve as a reference method by which lamb carcasses can be sorted and priced based on their market value. They also have to provide transparency of the market chain from the consumers to the producers so as to encourage production of carcasses of better quality (less fat and greater lean meat yield).

In the EU, there are no mandatory regulations for lamb carcass classification and, in the past, different carcass classification systems have been used by different countries. However, most of the European countries use a subjective visual scheme based on the EUROP conformation grading system and a visual assessment of fat cover using a numeric fat score. In Australia, there has been no widespread use of a conformation classification system but instead the use of weight and fat score grids has been the common payment system until very recently. In 2005, seven large abattoirs in Australia installed VIAscan® technology. This allows meat processors to pay farmers according to meat yields as opposed to carcass weights and aims to provide a more objective feedback to farmers and better returns to producers that consistently produce higher yielding carcasses (Meat Info 2006). In the same year

NZ had eight VIAscan® units installed with another four more units in the process of being installed. This methodology also replaces the previous system in NZ where payments were based on weight and total tissue depth (fat) of the lamb carcass over the 12-13th rib known as the GR (grade rule) measurement. More recently an article published at Farmonline (2009) reported that the Australian sheep industry is willing to use this technology as a tool to guide producer to improve carcass quality through genetic selection

In the UK, the current evaluation of carcass value is based on assessment of conformation and fat class according to the Meat and Livestock Commission's (MLC) Sheep Carcass Classification Scheme by an expert grader in the abattoir (Figure 1.2). Carcass conformation is assessed using the EUROP five-point scale (where "E" is for excellent and "P" is for poor conformation), and fatness, using a five-point scale from 1 (leaner) to 5 (fatter), with scores 3 and 4 sub-divided into "L" (leaner) and "H" (fatter) (Anderson 2003). In addition to the conformation and fat class, carcasses are also classified by: (i) weight – cold dressed carcass weight, (ii) dressing specification used, and (iii) category (new and old season lamb, mature sheep). The scheme is designed to describe the main characteristics of the carcass without attributing any qualitative judgement (Jones *et al.* 2003).

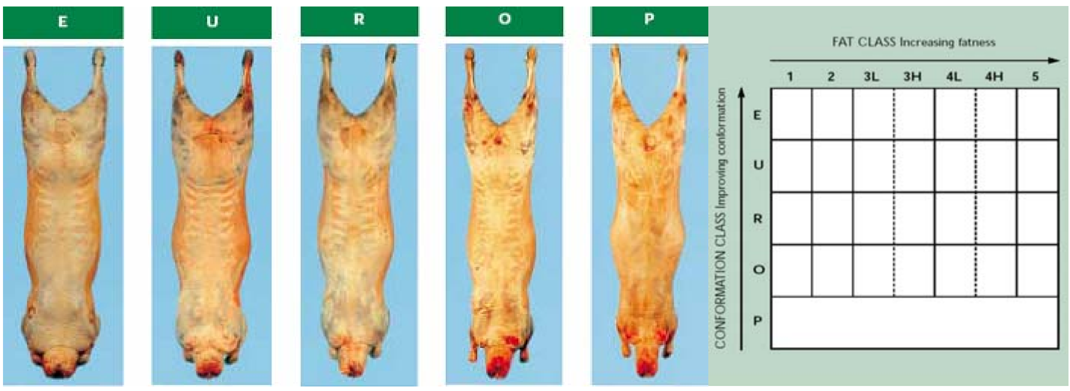

Figure 1.2 MLC carcass classification scheme based on the EUROP scale and MLC's EUROP and fat class grid (Anderson 2003)

Evaluation of carcass quality using MLC's carcass classification scheme for conformation and fat class scores (MLC-CF) has been an important tool for ensuring fair payment to producers and it also contributes to transmit the consumer's needs through the supply chain. However, subjective systems, such as the MLC-CF scores, are more likely to show variability between classifiers. In addition, the subjective carcass grading system has been reported to be a poor predictor of percentage of lean meat yield in lamb carcass (Johansen *et al.* 2006). Therefore, the establishment of objective payment systems that can accurately reward carcass value is of enormous importance to the sheep industry in many countries.

Automated systems that could provide objective measures of carcass quality with high repeatability have been increasingly studied and have mainly focused on the use of VIA systems (Figure 1.3). This technology offers a fast and automatic method of objectively assessing carcass quality with the potential to improve accuracy and precision of prediction of carcass composition (Horgan *et al.* 1995; Hopkins 1996; Hopkins *et al.* 2004). Additionally, this technology could enable processors to classify products for different markets, thus improving product consistency and providing the consumer with better product information.

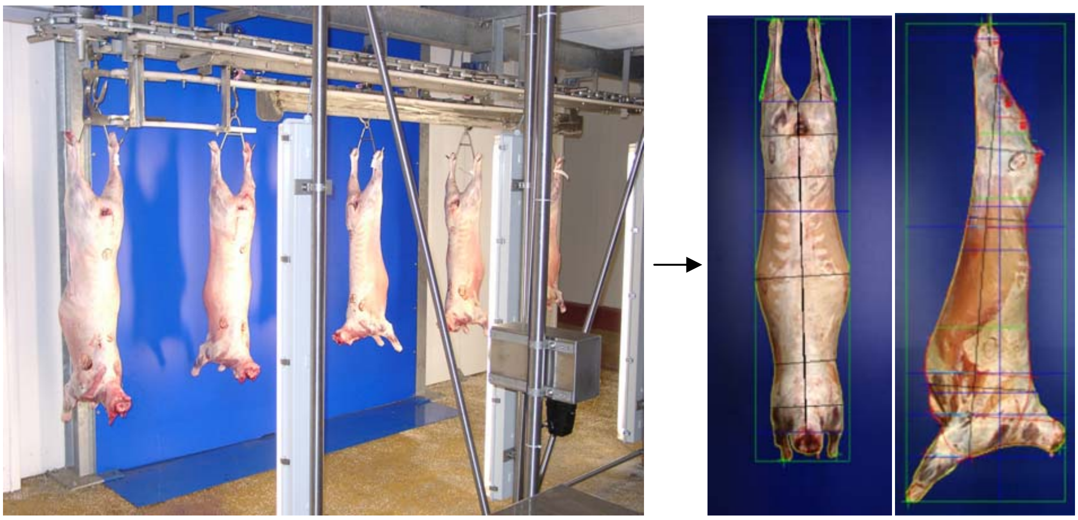

Figure 1.3 Video image analysis station for lamb carcasses (VSS2000) (left figure source: www.eplusv.de)

As with *in vivo* methods, it is desirable that methods of assessing carcass composition *post mortem* be precise and accurate. Computer tomography and MRI are highly precise methods but are too slow for online use, even if they were cost effective. Video image analysis (VIA) based systems used to estimate carcass value have been studied for the beef, pig and lamb industry (Horgan *et al.* 1995; Stanford *et al.* 1998; McClure *et al.* 2003; Allen 2003; Steiner *et al.* 2003a; Hopkins *et al.* 2004). Using pork carcasses, McClure *et al.* (2003) reported that a VIA system, the VCS2001 (E+V Technology GmbH), could predict weights of various retail products (saleable product, fat-corrected lean, bone-in ham, bone-in loin, loin lean, and belly) with high levels of accuracy. In beef cattle, Borggaard *et al.* (1996) presented high accuracies (0.66 – 0.85) for prediction of rib eye area, percentage of saleable meat and meat yield from the hind leg. A few years later, Steiner *et al.* (2003a) reported high levels of accuracy and repeatability using a VIA system in beef to estimate *longissimus muscle* area. In lamb, previous studies (Horgan *et al.* 1995; Hopkins 1996) have already emphasized the potential of VIA systems for predicting commercially important characteristics. Using a similar patented technology (VIAscan®, Meat and Livestock Australia), Hopkins *et al.* (2004) reported a significant ability for predicting percentage of lean meat yield in lamb carcasses under commercial conditions, with the system showing potential to be installed online in abattoirs. Other studies (Brady *et al.* 2003; Cunha *et al.* 2004) have also suggested image analysis could be used as a method for pricing lamb carcasses, contributing to the transparency of the market.

In comparison with the subjective carcass classification system, VIA was demonstrated to improve prediction of most aspects of lamb carcass composition (Horgan *et al.* 1995). In that study, VIA carcass shape measurements, along with carcass weight and sex, predicted saleable meat yield with greater accuracy (R^2 = 0.95) than the current subjective system used in the UK along with carcass weight and sex (R^2 = 0.94). However, there were major differences in the prediction of fat with higher accuracy achieved by the automatic assessment (R^2 = 0.58) compared with the subjective method (R^2 = 0.45). Using lambs of diverse ages, breeds and sexes, Stanford *et al.* (1998) reported that the accuracy of prediction of saleable meat yield was higher when using VIA colour and shape variables for warm carcasses along with carcass weight compared to the GR and subjective conformation scores used in the Canadian classification system. In the same study, the proportion of waste fat and bone dissected from the carcass together with proportions of total carcass weight contained in the leg and shoulder were also accurately predicted by VIA, although the total carcass weight contained in the loin could not be well predicted. The American assessment of lamb carcasses (USDA Yield Grades) was also compared with the outputs of a lamb vision system (LVS; Research Management Systems U.S.A., Fort Collins, CO) (Cunha *et al.* 2004). Variables from VIA measurements, along with hot carcass weight, explained 68, 62 and 74% of the observed variability in saleable meat, subprimal and fat yields respectively. This represented a significant improvement over the use of USDA yield grades (59, 59 and 65%) in the ability to predict percentage yields of lamb carcasses. Furthermore, some studies also reported high repeatability estimates (> 0.94) for the assessment of *longissimus* muscle area in beef and lamb using a VIA system (Steiner *et al.* 2003a; Cunha *et al.* 2004).

Recently, a VIA system was evaluated for its ability to predict fat class as measured by the MLC scoring system under commercial conditions of an abattoir in the UK (Industry Report 2007). In that report, the results from the VIA system disagreed slightly with the results from the MLC graders on fat scores. Although using subjective MLC scores as a reference method to calibrate and validate a VIA system might be questionable, the conclusion was that VIA was less accurate in predicting fat class compared to in-plant MLC classifier. However, an augmentation of VIA systems to improve the prediction of carcass fatness might be made possible by the incorporation of a grading probe. Using an optical visible light reflectance probe, Kongsro *et al.* (2009) reported accurate predictions of fat tissue ($R^2 > 0.90$) in Norwegian lamb carcasses. This technology is fast and could easily be incorporated into a VIA system.

In addition to providing the basis for a payment system based on meat yield, the use of a VIA system on lamb carcasses may also offer the possibility to help estimating other carcass and meat quality traits in a non-destructive and cost-efficient way. VIA scanning of live lambs has also been shown to contribute in the prediction of meat quality by estimating intra-muscular fat (Lambe *et al.* 2008b). In addition, there are an increasing number of methods which are being or have been developed to objectively measure meat quality traits. The majority of these biophysical methods are invasive and can measure a series of sensory and physical parameters (Damez and Clerjon 2008) and could be used together with the VIA system to provide in addition, measures of meat quality. A recent study also concluded that a near infrared spectral reflectance system (NIR) offers an in-plant opportunity to sort carcasses into tenderness product groups for guaranteed-tender branded beef programs (Rust *et al.* 2008).

1.4 Genetic evaluation of carcass quality

The UK sheep breeding industry is characterised by a stratified crossbreeding structure which uses a variety of breeds adapted to the different climates and landscapes (upland, lowland) to produce slaughter lambs. Hill sheep make use of harsh hill environments as they are hardy enough to survive. After around four lamb crops, the hill ewes are often drafted down to upland areas where they are crossed with Longwool sires, which are mainly Bluefaced and Border Leicester, to produce Mule ewes. Longwool sires add prolificacy and milkiness to the hardiness of the hill breeds making the Mule ewes a useful maternal crossbred animal. These Mule ewes are then mated to terminal sire breeds in both upland and lowland environments to produce slaughter lambs which have good growth and carcass traits from the terminal sire. Approximately 71% of the slaughter lambs in the UK are produced through the crossbred between Mule ewes and terminal sire breeds (Pollott and Stone 2006). Slaughter lambs produced from hill breeds account for approximately 16% of the total and the other part of slaughter lambs are produced from Longwool breeds.

This particular stratified production system has influenced the way sheep breeding programmes have been developed. While the main drive of the UK sheep industry is the sustainable production of lamb meat, it is also very important to maintain good maternal ability, especially for the breeds kept in harsh climate conditions. Therefore, the use of multi-trait selection indexes to improve maternal and carcass traits have been used in the UK sheep industry since the 1970s (Simm and Dingwall 1989). In 2001, new breeding indexes were introduced which allowed for improving carcass and maternal traits simultaneously in hill flocks (Conington *et al.* 2001). These indexes aim to balance the need to improve carcass quality while maintaining maternal characteristics and disease resistance (Conington *et al.* 2006). Although breeding goals for carcass traits are part of the overall economic merit of the hill breeds, 71% of total lambs born in Britain are sired by terminal sire breeds contributing to a 44% of the genes of the slaughter lambs (Pollott and Stone 2006). Therefore, the value of improving carcass quality through genetic improvement of terminal sire sheep has long been recognized and is the main source of genetic improvement for carcass traits in the UK sheep industry (Simm *et al.* 2001).

Selection goals for terminal sire breeds usually include growth and carcass composition. While performance traits (weight and growth rate) can be easily recorded on individual candidates for selection, carcass composition must be measured indirectly, or on relatives of the candidate animals. *In vivo* estimates of carcass composition are possible with the use of technology such as ultrasound and CT. Ultrasound scanning of the loin provides measurements of subcutaneous fat depth and muscle depth at the third lumbar vertebra. Since the late 1980s, these ultrasound measurements and live weight have been used in British terminal sire sheep breeding programmes as selection criteria to increase the weight of lean meat while limiting any increase in the weight of fat at a given age (Simm and Dingwall 1989). While the use of this index (Lean Growth) resulted in a good response to selection for improved carcass composition (Simm *et al.* 2002), the incorporation of CT can result in an increase in genetic progress (by up to 50%) compared to using ultrasound measures alone (Lewis and Simm 2002).

Although CT has been shown to be very accurate for predicting the weight of muscle, fat and bone tissues (Lambe *et al.* 2003; Macfarlane *et al.* 2006), it is also an expensive and time consuming technique, which restricts its use on a large scale.

Therefore, the use of CT scanning in the sheep industry is optimised in a two-stage selection process. This strategy involves an initial screening of all selection candidates using ultrasound scanning. The top animals ranked by the information recorded from ultrasound in the first stage are then CT scanned. The best rams for breeding are then selected after completing the second stage.

1.5 Use of VIA in sheep breeding programmes

Genetic improvement programmes for sheep in the UK are continuously evolving to ensure highly efficient production of quality lamb in order to satisfy the consumer's demands while economic returns to the producers are maximized. The use of technologies, first ultrasound and lately also CT, for the indirect evaluation of carcass composition has accelerated the genetic improvement of these traits (Young *et al.* 1999; 2001; Macfarlane 2006).

Currently, genetic improvement programmes for carcass composition are based on the selection of purebred terminal sire breeds to improve carcass composition of crossbred slaughter lambs. Genetic evaluations that combined purebred and crossbred data have shown to increase the accuracy of evaluation of purebreds and the performance of crossbred animals (Bijma and van Arendonk 1998; Lutaaya *et al.* 2002). However, the incorporation of this information into breeding programmes is currently compromised, firstly by the limitations on how individual carcass data can be collected and secondly by the type of measurements used to assess carcass quality.

Carcass dissection provides accurate measures of lean meat, fat and bone in the whole carcass and in the joints; however, the routine collection of these data within abattoirs operating commercially is not time- or cost-effective. Conformation and fat scores routinely collected in the abattoir could provide a fast and cost-effective way of recording carcass traits data. However, carcass conformation has been found to be a poor predictor of saleable meat yield, lean content and lean to bone ratio (Kempster and Cuthbertson 1977; Kempster 1981) and is positively correlated with measures of fatness both genetically and phenotypically (Lewis *et al.* 1996; Conington *et al.* 1998; Jones *et al.* 1999; Moreno *et al.* 2001; Karamichou *et al.* 2006). Therefore, current measures of conformation and fatness available in abattoirs have a restricted role in selection programmes that aim to breed for reduced fatness and increased lean tissue growth rate.

The potential introduction of VIA systems in UK abattoirs might trigger the development of a payment scheme based on weight of primal joints. Accurate estimates of primal joint weights, which can be electronically retrieved using a VIA system installed online in abattoirs (Horgan *et al.* 1995; Cunha *et al.* 2004), could provide an efficient integration of these traits into genetic evaluations to increase the reliability of purebred evaluation and as a consequence improve carcass traits of high economic market value in the slaughter lamb.

1.6 Molecular genetics in sheep breeding

Recent developments in DNA technologies have made it possible to identify DNA polymorphisms affecting the phenotype for economically important traits. The use of such molecular information (markers) to identify the associated alleles or chromosomal segment/s and to select breeding stock based on this information, is known as marker-assisted selection (MAS). This utilization of molecular information via MAS is being increasingly applied to sheep breeding programmes with the focus of improving traits such as carcass and meat quality (Meuwissen and Goddard 1996; Nicoll 2007), where direct measures cannot be taken on the selection candidates themselves (Dodds *et al.* 2007).

During the past ten years, several quantitative trait loci (QTL) for carcass traits in sheep have been identified (e.g.Cockett *et al.* 1994; Nicoll *et al.* 1998; Walling *et al.* 2004) but, to date, the use of this molecular information in MAS at a commercial level in sheep breeding is still limited. Increased knowledge of the nature of markers and genes, together with a decline in price of this technology, is starting to change this situation and is beginning to affect the sheep breeding industry. In a study by Laville *et al.* (2004), a QTL on chromosome 2 (OAR 2) for generalised muscular hypertrophy in crossbred lambs was found to have a significant effect across a large range of carcass characteristics. In their study, the QTL effect was significantly associated with an increase in conformation score and weight of the total carcass, as well as weights of the shoulder, lumbar and leg regions. Recently, the genetic basis of the segment of OAR 2 associated with this muscle growth has been identified (Clop *et al.* 2006) and is now being commercially exploited in Australia and New Zealand, and is under investigation in UK flocks (Hadjipavlou *et al.* 2008). The use of molecular information in sheep breeding programmes involves an extra economic cost. Therefore, for this technology to succeed in the sheep industry, the producer needs to be rewarded for any increase in carcass value achieved through the use of molecular techniques.

In the UK, recent studies identified several QTL affecting muscle growth in sheep, which varied considerably in magnitude. One of them was mapped on OAR 18 by Walling *et al.* (2004) in a Texel sheep population. This QTL increases eye muscle depth by 4 to 8%, providing an opportunity to increase the efficiency of selection programmes for increased loin muscling. This QTL was later confirmed by another study (Matika *et al.* 2006) and is currently known as the TM-QTL (short for Texel muscling-QTL). A recent study by Macfarlane *et al.* (2008) reported effects of the TM-QTL on carcass traits measured *in vivo* by CT and post-slaughter by carcass dissection, in a population of crossbred lambs.

These QTLs, and their underlying genes, could help to provide a way to improve carcass traits via MAS, as well improve understanding of animal growth (muscle and fat) and its complex associations with other traits, but this requires knowledge of the genes involved, their frequencies, their direct, pleiotropic and epistatic effects and their interactions with the environment. The use of molecular information could help to select for traits that are difficult or expensive to measure. Therefore, progress towards including molecular information in breeding programmes may help to select animals for better efficiency and sustainability of lamb production by improving carcass quality (i.e. reducing fatness and improving lean tissue growth and muscularity) without compromising meat quality or maternal traits. However, realising the value of a muscle enhancing QTL for the sheep industry relies on a carcass grading system that can quantify any resulting increase in muscle tissue, with the aim of rewarding farmers for their increased product quality.

1.7 Conclusions

In the future, it is likely that new measurement techniques, such as VIA and genomic markers, will both be used in breeding programmes to improve carcass and eating quality traits. But before that, the accuracy, precision and consistency of the VIA systems in the prediction of carcass quality characteristics such as meat yield needs to be investigated. Then, the genetic parameters of VIA traits need to be estimated for its use in breeding programmes. Besides, the capabilities of the VIA system in the detection of increased carcass value by the use of molecular techniques need to be explored so that producers are fairly rewarded.

1.8 Thesis outline

Most of the data analysed in this thesis was collected over the three years of the thesis work. During the first six months, the VIA system (VSS2000, E+V Technology GmbH) was calibrated and validated for the prediction of carcass conformation, fat and meat yield of different primal cuts. The VIA data for Chapter 2 was obtained from a commercial lamb population. Data for Chapters 3, 4 and 5 were crossbred slaughter lambs from experimental populations.

The Chapters of this thesis describe the scientific work that was undertaken to investigate the ability of a VIA system to predict carcass quality traits and its use in genetic improvement programmes.

In Chapter 2, the accuracy and precision of a VIA system in the prediction of weight of primal joints was investigated and compared with MLC-CF scores (conformation and fat). A commercial dataset of 440 lamb carcasses was used to evaluate the phenotypic associations between results of carcass dissection of leg, chump, loin, breast and shoulder primal joints with estimates of these primal meat yields using VIA or MLC-CF scores for conformation and fatness.

An independent dataset of 630 crossbred lambs, from where the VIA prediction models were derived, was used in Chapters 3 and 4 to estimate the genetic parameters of weight of primal joints (leg, chump, loin, breast and shoulder) as measured by VIA and MLC-CF scores. This same dataset was also used to estimate the genetic parameters of VIA carcass dimensional measurements in Chapter 4. A dataset of 6417 lambs born between 2000 and 2003 was available from a previous study and was used in Chapter 3 to estimate genetic parameters of performance traits. These 6417 lambs were related to the 630 crossbred lambs for which VIA data was collected and so the two datasets of 630 and 6417 could be combined into a unique dataset of 7074 to estimate the phenotypic and genetic correlations between VIA and performance traits.

A total of 166 crossbred lambs born in 2006 out of Mule ewes and sired by purebred Texel rams known to be heterozygous for TM-QTL were used in Chapter 5 to evaluate the effects of the TM-QTL on carcass and meat quality characteristics measured by MLC-CF scores and VIA.

Chapter 2

Evaluation of Video Image Analysis (VIA) technology to predict meat yield of sheep carcasses online under UK abattoir conditions

Abstract

The subjective Meat and Livestock Commission (MLC) carcass classification scheme and an automatic carcass grading system based on video image analysis (VIA) were compared for their ability to predict weights of primal carcass joints (LEG, CHUMP, LOIN, BREAST and SHOULDER). A total of 443 commercial lamb carcasses under 12 months of age and of mixed sex were selected according to their cold carcass weight (CCW), conformation and fat scores. Lamb carcasses were classified based on the MLC carcass classification scores for conformation and fatness (MLC-CF), scanned by the VIA system and dissected into primals. After adjustment for CCW, the estimation of primal joints using MLC-CF scores showed high coefficients of determination (R^2) in the range of 0.82 to 0.99. The use of VIA always resulted in equal or higher R^2. The precision measured as root mean squared error (RMSE) was 27% (LEG), 13% (CHUMP), 1% (LOIN), 11% (BREAST) 5% (SHOULDER) and 13% (total primals) higher using VIA than MLC-CF carcass information. Adjustment for slaughter day and sex effects indicated that estimations of primal joints using MLC-CF scores were more sensitive to these factors than those using VIA. This was consistent with an increase in stability of the prediction model of 28%, 11%, 2%, 12%, 6%, and 14% for LEG, CHUMP, LOIN, BREAST, SHOULDER and total primals, respectively, using VIA compared to MLC-CF scores. In conclusion, it is possible to improve the prediction of primal meat yields using VIA instead of the current the current MLC-CF carcass classification scheme used in the UK abattoirs.

2.1 Introduction

Accurate estimates of carcass composition and eating quality are important to assist in the development of a value-based marketing system in the lamb industry and to address increasing consumer demand for leaner meat. The evaluation of carcass quality using carcass classification systems has been an important tool to ensure fair payment to producers, and it also helps to communicate consumer's needs through the supply chain. Currently in the UK, the commercial value of a carcass depends mainly on its weight, but also on its conformation (shape) and fat cover, which are visually appraised by expert classifiers. This carcass evaluation system is based on the Meat and Livestock Commission's (MLC) fatness and conformation (MLC-CF) scoring scheme (Anderson 2003) and is a common system to assess product quality (Jones *et al.* 2003). Subjective based systems, such as the MLC-CF scores, are more likely to show variability between classifiers. Consequently, automated systems that could produce objective measures for the evaluation of carcass quality with higher repeatability have been studied increasingly. Alternative methods have mainly focused on the use of video image analysis (VIA) systems. This technology offers a fast and automatic method to objectively assess carcass quality with the potential of improving accuracy of carcass measurements. Additionally, this technology could enable processors to classify products for different markets, improving product consistency and providing the consumer with better product information.

Video image analysis based systems used to sort carcasses into current classification categories have been studied for the beef, pig and lamb industry (Horgan *et al.* 1995; Stanford *et al.* 1998; McClure *et al.* 2003; Steiner *et al.* 2003b). Previous studies (Horgan *et al.* 1995; Hopkins 1996) already emphasized the potential of VIA systems for predicting commercially important characteristics of lamb carcasses. However, this technology did not have commercial applicability due to its limitation for a full online installation in the abattoirs. Using a similar patented technology (VIAscan®, Meat and Livestock Australia), Hopkins *et al*. (2004) reported a significant ability for predicting lean meat yield in lamb carcasses under commercial conditions, with the potential to be installed online in abattoirs. Other studies (Brady *et al.* 2003; Cunha *et al.* 2004) have also suggested that image analysis could be used as a method for pricing carcasses, contributing to the transparency of the market.

A new reference payment system based on total meat yield of individual primal cuts could be developed. The introduction of an automatic technology may have considerable potential, as reported for VIA systems in other countries, for objective and accurate estimation of primal meat yields. To our knowledge, the commercial applicability of a VIA system in comparison to the current MLC-CF scores to predict carcass composition and meat yield distribution has not yet been investigated. Therefore in the current study a VIA system was calibrated and validated under commercial conditions in a UK abattoir. The calibration and validation test allowed the development of prediction models to estimate primal meat yield of various carcass cuts by the VIA manufacturer. In the current study, the potential of the VIA system for the prediction of meat yield of various lamb carcass joints under UK commercial conditions has been investigated and compared to the current MLC-CF carcass classification scheme.

2.2 Materials and methods

2.2.1 Experimental design

A commercial sample of 443 lamb carcasses (crossbred) was used in this study. Lambs were under 12 months of age at slaughter day and of mixed sex. Carcasses were selected according to their cold carcass weights (CCW), conformation and fat scores to represent, as far as possible, the full range of lambs slaughtered in the UK. Extreme carcasses (very lean or fat and of high or low conformation) were also included in the evaluation to ensure a robust and representative dataset.

Lambs were slaughtered under commercial conditions in a large abattoir in North Wales (Gaerwen), and were presented in a standardized position with the legs spread apart (on a gambrel) and shoulders banded. The following information was taken for each carcass: (i) CCW; (ii) standard MLC-CF (7-point fat and 5-point conformation) scores and; (iii) VIA scan of back and side views. The MLC classification scheme is based on the EUROP scale to describe conformation (shape of carcasses) from E (excellent) to P (poor) and the fat cover of the carcass in a range from 1 (very lean) to 5 (very fat). Classes 3 and 4 are subdivided into: 3L, 4L (leaner) and 3H, 4H (fatter) (Anderson 2003). To reduce errors in the evaluation, lamb carcasses in the present study were assessed offline for conformation and fat by one MLC expert classifier. A reference panel with more than one assessor may account for variation between classifiers (Allen 2003), but, in the present study, a highly qualified MLC expert classifier was chosen to represent an expert panel.

After lambs were assessed based on the MLC-CF classification scheme, they were redirected from the main slaughter line to the VIA system for scanning. The VIA system for lamb (VSS2000) developed by E+V Technology GmbH (http://www.eplusv.de/) was available in the present study. The VIA system was experimentally installed off the main slaughter line in the abattoir to facilitate the calibration and validation of the system. However, it was adjusted to the same speed as the actual slaughter line to reproduce the same online conditions as in the abattoir (800 carcasses/h). Before scanning, the VIA equipment was calibrated against white templates, as shown in Figure 2.1 which served as a reference for the VIA measurements taken on the slaughter lambs used in this study.

After the adjustment of the VIA scanning, two images were taken from each carcass: first from the back, then from the side (Figure 2.2). The images were taken on the carcass assessment unit of the VSS2000 which consists of: (i) stationary image capture devices (cameras 0 and 1) with standardized lighting; (ii) image processing and analyzing software; (iii) a metal structure and chain to move carcasses through the VIA station.

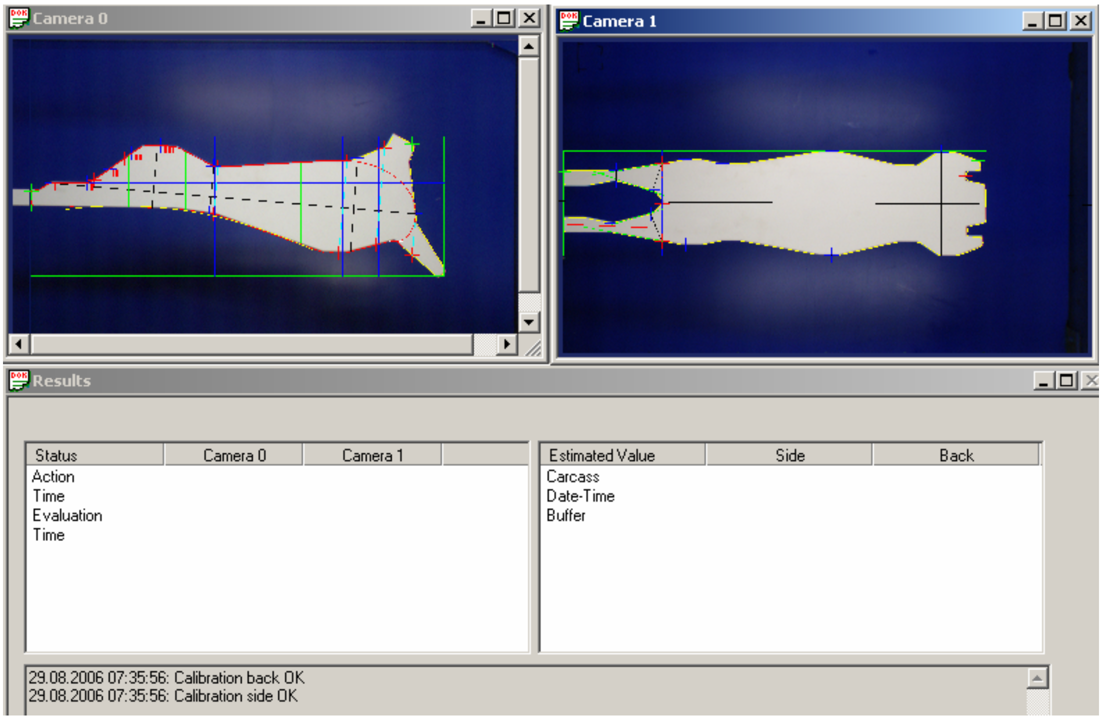

Figure 2.1 White carcass templates for the calibration of the VIA system before scanning.

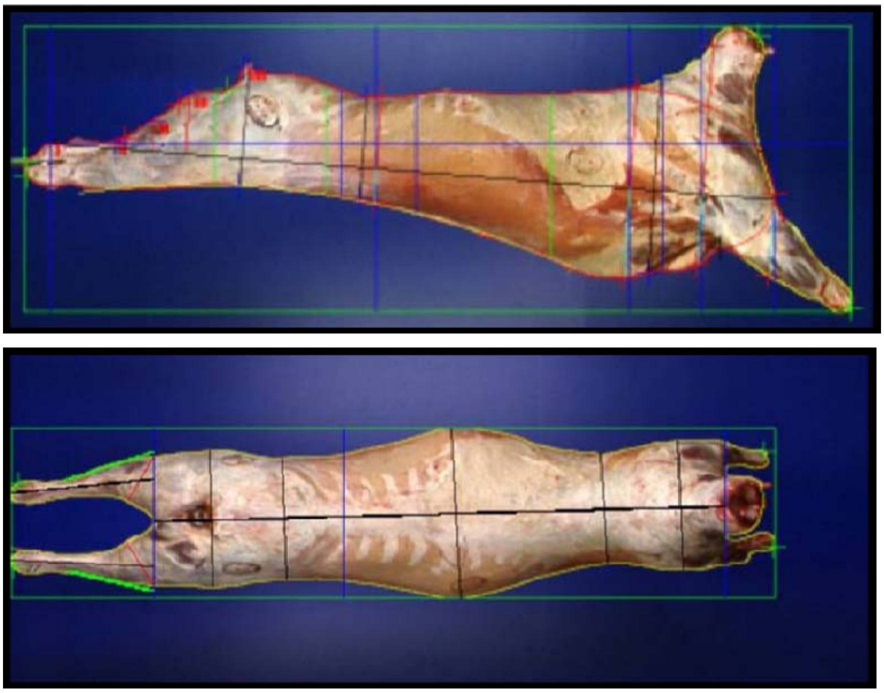

Figure 2.2 Reference points of the back view for dimensional measures using the VIA system VSS2000 (www.eplusv.de)

2.2.2 Carcass scanning and image analysis

The carcass identification number together with a visual assessment of fat colour on a scale from 1 to 3 (white, cream and yellow), as well as dressing damage and bruising on a scale from 1 to 3 (mild, moderate and severe) at specific locations on the carcass (hind legs, saddle, including breast and fore legs) were recorded by the same assessor on all the carcasses before VIA scanning. An image number for each carcass was generated by VSS2000. VIA system measurements included dimensional characteristics of the carcass and colour variation at selected positions. The software captures the image and divides the carcass into different anatomical regions, which include lengths, widths and calculated areas. The reference points of these regions (Figure 2.2) served as a basis to make a large series of carcass measurements, which were then used as system output variables to describe the shape and size of the carcass and then predict the weight of primal carcass cuts. The relative proportions of fat were calculated from the pixel colour values extracted from the image. The percentage of different colour pixels allowed E+V Technology to calculate the level of carcass fatness. Parallel to this study, the industry partners of this project assessed the potential of the VIA system for the prediction of conformation and fat class compared to the MLC expert classifiers. The percentage of agreement between the VIA and the expert was of 80% for conformation and 70% for fat class and therefore was concluded that VIA achieved the target accuracy for conformation but in general did not meet the target accuracy for predicting fatness. The prediction of fatness was a key objective of the industry trial, whereas the present study focussed on the ability of E+V Technology to predict weights of carcass primal cuts from line measurements and cold carcass weight. The dissected primal cuts used for the calibration of the VIA system were obtained under industry butchery specifications. These are described in more detail in the section below (*2.2.3 Carcass dissection*). A series of VIA measures (carcass lengths, widths and areas) obtained by image analysis (Figure 2.2) were used by E+V Technology to derive industry-based prediction equations for weights of primal carcass joints (referred to in the following as LEG, CHUMP, LOIN, BREAST and SHOULDER) and total primals. The VIA estimates of primal joints from E+V Technology were used in the present study and will be referred to as VIA-primals. Regression equations between weights of dissected primal joints and VIA-primals and MLC-CF scores were used to determine the accuracy and precision of the VIA system in comparison to the MLC-CF classification scheme. The effects of fat colour, bruising and dressing damage were used by E+V Technology to help develop the prediction equations for primal meat yields.

2.2.3 Carcass dissection

A total number of 443 lamb carcasses were dissected at the Welsh Country Foods abattoir using industry butchery specifications. On a weekly basis, approximately 60 carcasses were collected over a two- or three-day period (Monday to Wednesday) and then butchered on the fourth day (Thursday).

In order to minimize butcher-associated variability, the work was undertaken by the same small team of three plant butchers dissecting the same part of the carcass and supervised by a single MLC technologist. Carcasses were split first into primal cuts, fore-end (shoulders), saddle (loin and breast) and hind legs. The fore-end was removed by cutting between the 6th and the 7th rib and the hind legs were removed by cutting between the 5th and the 6th lumbar vertebra. The fore-end, saddle and hind legs sections were then split into right and left sides and the individual weights recorded. The primal cuts were then trimmed to a pre-retail level with external (subcutaneous) fat trimmed to a maximum of 6 mm at any point on the cut to obtain the trimmed primal cuts LEG, CHUMP, LOIN, BREAST and SHOULDER (Figure 2.3).

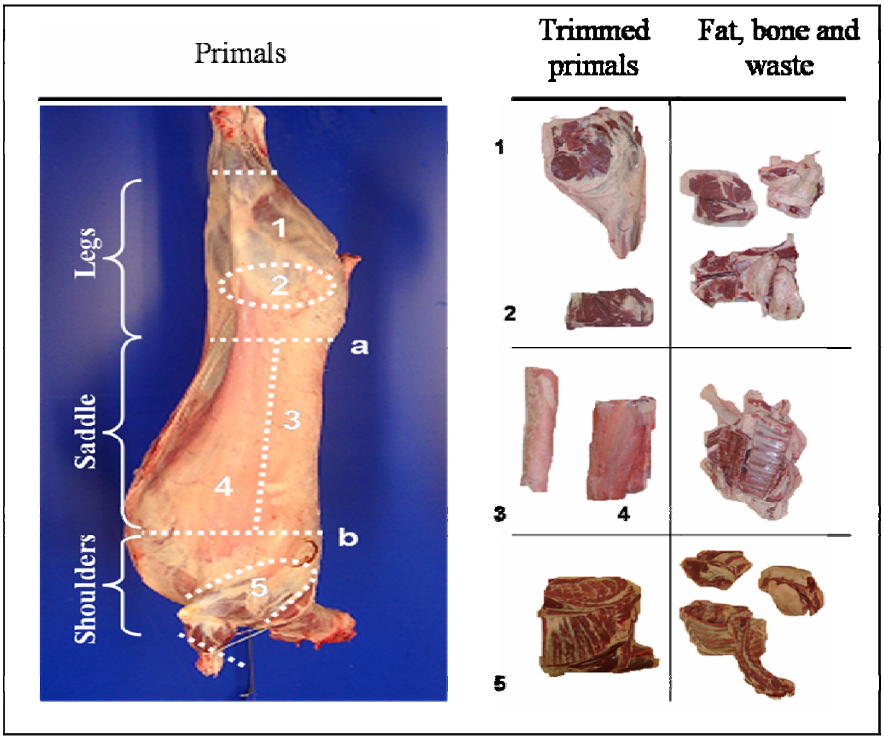

Figure 2.3. Lamb carcass dissection into primal cuts, legs (cutting point "a" between the 5th and the 6th lumbar vertebra), saddle and shoulders (cutting point "b" between the 6th and the 7th rib) and pre-retail trimmed primal cuts, LEG (1), CHUMP (2), LOIN (3), BREAST (4) and SHOULDER (5) together with the residuals from the trimming procedure, mainly fat, bone and waste.

Leg joints were removed by cutting and sawing in an approximately 12 mm straight line below the aichbone through the base of the tail. The knuckle was removed from the tibia (below the *calcaneal tuber*) and the aichbone was then removed from the legs. Any loose meat and any remaining channel fat were separated into fat, bone and waste. The CHUMP joints were separated into boneless CHUMP by cutting through the hipbone (*ischium and ilium*) and the point end of the CHUMP. The crown fat and breast flap and the point end of the CHUMP were separated into lean and fat trim. The left and right saddles were separated into LOIN and BREAST joints by cutting a parallel cut to the back bone from a point approximately twice the length of the eye muscle at the anterior end (best end of neck) of the LOIN. The LOIN joints were removed by sheet boning the bones that are normally attached to the breast. Half the length of the rib bones were removed by cutting to a maximum of 35 mm from the chine bone and any excess fat and suet (kidney knob fat) spinal cord, skirts and blade bones were separated into fat, bone and waste. The shoulder flap (point of the BREAST) was squared off and separated into lean trim. The back strap (*ligamentum nuchae*) and the knuckle ends (50 mm above the joint at the lower end of the *radius* and *ulna*) were removed from the shoulder joints and separated into bone trim. There was no subcutaneous fat removed from the shoulders to obtain SHOUDLER trimmed primal cut.

All the lean, fat, bone and waste derived from the trimming of the five primal cuts was weighed and added to the weight of the primal joints and the sum of all the components was compared against the CCW (mean = 19.45 kg, minimum = 7 kg, maximum = 35.6 kg). A difference of ≥ 500 g, which accounts for an average of 2.5% of the total carcass weight, was considered an error in the procedure, and the sample was rejected. The total primal meat yield was calculated as the sum of all primal components weights.

2.2.4 Statistical analysis

Regression analyses were used to regress dissected primal joints (LEG, CHUMP, LOIN BREAST and SHOULDER) and total primals on the independent variables of MLC-CF scores or VIA-primals by using the general linear model procedure (GLM) of SAS package for Windows Release 9.1 (SAS Institute Inc., Cary, NC, USA). The following two models based on MLC [1] or VIA [2] carcass information were used:

$$Y_{ijk} = \mu + CONFORMATION_i + FAT_j + b_1(CCW_{ijk}) + e_{ijk}, \quad [1]$$

$$Y_i = \mu + b_1(VIAprimals_i) + e_i, \quad [2]$$

where $\boldsymbol{Y_{ijk}}$ and $\boldsymbol{Y_i}$ are the vectors including dissected weights of primal joints. The first multivariate model included the MLC-CF scores of both $\boldsymbol{CONFORMATION_i}$ (5 classes: 1, poor conformation to 5, excellent conformation) and on $\boldsymbol{FAT_j}$ (7 classes:

1, very lean to 7, very fat). The second univariate model, which included the VIA estimates of primal cuts weights (***VIA-primals$_i$***) was applied six times to regress, one at a time, the five VIA primals (VIA-leg, VIA-chump, VIA-loin, VIA-breast, VIA-shoulder and VIA-total primals) against the corresponding dissected primal joints (LEG, CHUMP, LOIN, BREAST and SHOULDER). Model 1 (MLC-CF scores) was adjusted by ***CCW$_{ijk}$***. Estimates of primal joints, obtained using MLC-CF scores and VIA-primals in the model, were compared with the values measured by dissection using the coefficient of determination (R^2) to evaluate the accuracy of the prediction models above (1 and 2). Root mean squared error (RMSE), as defined in the equation below, was used to determine the precision in the prediction models (1 and 2).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{df}} \text{ ,}$$

where ***n*** is the number of samples in the dataset, ***df*** is the degrees of freedom in the model, $\boldsymbol{y_i}$ is the observations in the dataset and $\boldsymbol{\hat{y}_i}$ is the predicted values of the observations.

Additionally, the influence of slaughter day (***sd$_i$*** (10 classes)) and ***SEX$_j$*** (2 classes: males and females) of the lamb on the estimation of primal joints and total primals from MLC-CF or VIA carcass information was examined using the following two models:

$$Y_{ijklm} = \mu + sd_i + SEX_j + CONFORMATION_k + FAT_l + b_1(CCW_{ijklm}) + e_{ijklm} \text{ ,} \qquad [3]$$

$$Y_{ijk} = \mu + sd_i + SEX_j + b_1(VIAprimals_{ijk}) + e_{ijk} \text{ ,} \qquad [4]$$

Interactions among fixed effects were non-significant. A high reduction of RMSE by adjusting for slaughter day and sex implies a high sensitivity of the estimation of primal joints and total primals from MLC-CF or VIA carcass characteristics.

Therefore, the preferred system would have a low RMSE before adjusting for slaughter day and sex and the RMSE would not reduce when accounting for these effects in the model (robust estimation).

Prediction models were further tested with respect to their stability using a cross-validation analysis implemented in the Partial Least Square procedure (PLS, SAS Institute Inc., Cary, NC, USA). The PLS cross-validation method 'leave-one-out' was used, which consisted in leaving one observation out as a single element test set, while all the other observations were used for the estimation. This procedure was then repeated as many times as there were observations in the dataset, minus 1. Other studies have reported the use of this PLS procedure as a validation method for testing the stability of prediction models for evaluation of lamb carcass composition (Johansen *et al.* 2006) as well as drip loss in pig carcasses (Forrest *et al.* 2000). The stability using MLC-CF or VIA information for primal joints and total primals was based on models 1 and 2, i.e. on MLC-CF or VIA information and CCW and without considering variation due to slaughter day and sex, as it is the case under practical conditions.

In contrast to the RMSE defined above and used as a measure of precision in the dataset, the root mean squared error of cross-validation (RMSECV) defined below was used as a diagnostic tool to compare the stability of the models (1 and 2). Additionally, in Table 2.4, the RMSECV divided by the standard deviation (RMSE/SD) was used as a measure of precision independent of the traits units, which makes it possible to compare precision between primal cuts. RMSECV is calculated as:

$$RMSECV = \sqrt{\frac{PRESS}{n}},$$

where ***PRESS*** is the prediction residual sum of squares given by the PLS output and ***n*** is the number of samples in the dataset. Values of RMSECV and R^2 were used to estimate the stability of the models with high values of R^2 and low values of RMSECV indicating higher stability.

2.3 Results and discussion

2.3.1 Description of carcass information

The distribution of carcasses into conformation and fat classes as used by MLC is presented in Table 2.1. Most carcasses were scored in conformation classes R (35%), O (23%) and U (20%), whereas the fat scores were similarly distributed over all fat classes.

Table 2.1 Number of carcasses (percentage) allocated in each conformation and fat class using EUROP classification system assessed by an expert MLC assessor

Conformation score	Fat class							Sum
	1	2	3L	3H	4L	4H	5	
E	3 (0.7)	19 (4.3)	20 (4.5)	5 (1.1)	0	3 (0.7)	2 (0.5)	52 (11.7)
U	7 (2.6)	14 (3.2)	16 (3.6)	8 (1.8)	12 (2.7)	17 (3.8)	16 (3.6)	90 (20.3)
R	10 (2.3)	11 (2.5)	14 (3.2)	21 (4.7)	36 (8.1)	31 (7.0)	31 (7.0)	154 (34.8)
O	23 (5.2)	15 (3.4)	13 (2.9)	17 (3.8)	12 (2.7)	17 (3.8)	4 (0.9)	101 (22.8)
P	33 (7.5)	12 (2.7)	1 (0.2)	0	0	0	0	46 (10.4)
Sum	76 (17.2)	71 (16.0)	64 (14.5)	51 (11.5)	60 (13.5)	68 (15.4)	53 (12.0)	443 (100)

The cold carcass weights of the 443 lambs were approximately normally distributed with a mean value of 19.45 kg and a standard deviation of ± 3.83 kg. The CCW was in the range of 7 kg to 36 kg, with a coefficient of variation of 20%. Mean values, standard deviations and coefficients of variation of the various carcasses' joint measurements are shown in Table 2.2. Coefficients of variation were large and always above 19% for the primal cuts and total primals.

Table 2.2 Means, standard deviations (SD) and coefficients of variation (CV, %) for dissected primal joints and total primals†

	Mean	SD	CV
Cold carcass weight (kg)	19.45	3.83	20.00
Primals (kg)			
LEG	4.36	0.84	19.36
CHUMP	0.73	0.17	23.36
LOIN	2.87	0.63	21.55
BREAST	1.51	0.41	27.31
SHOULDER	4.98	1.06	21.32
Total primals	14.45	2.93	20.29

† Sum of trimmed primal cuts

2.3.2 Estimation of trimmed primal cuts using MLC-CF scores and VIA carcass information

Prediction accuracies of primal joints and total primals by MLC-CF scores (without CCW) were moderate, with R^2 ranging from 0.31 to 0.51 for primals LEG and CHUMP, respectively (Table 2.3). The precision of estimating these carcass cuts was low as indicated by a high RMSE ranging from 0.122 to 2.284, which represents 0.71 to 0.78 phenotypic standard deviations of these traits. These results indicate that MLC-CF scores without including CCW in the model are poor predictors of primal meat yields and agree with those reported in previous studies (Kempster 1981;

Horgan *et al.* 1995) on the ability of subjective methods for evaluating carcass composition. Subjective assessments alone have been useful predictors of carcass composition only when the lamb samples showed a high variation regarding breed type, age or size (Jones *et al.* 1993; Stanford *et al.* 1997). In more homogeneous batches of lambs, subjective evaluations alone have been poor predictors of carcass composition (Kempster 1981; Horgan *et al.* 1995), as reported in the present study.

As expected from the high correlation between CCW and the weight of primal cuts, significant improvements in accuracy and precision were observed across all carcass joints when the prediction equation, using MLC-CF carcass information, was adjusted for CCW (Table 2.3). The coefficient of determination (R^2) for the estimation of primal joints and total primals, after adjustment for CCW, was high, ranging from 0.82 to 0.99. Lower accuracies were reported by Horgan *et al.* (1995) with R^2 ranging from 52% to 76% of the observed variation using MLC-CF carcass information and accounting for sex and CCW. After prediction equations were adjusted for CCW, the precision of the estimation of primals and total primals from MLC-CF scores increased as indicated by a reduction in RMSE of 70%, 61%, 57%, 42%, 72% and 87% for LEG, CHUMP, LOIN, BREAST, SHOULDER and total primals, respectively. Improvements in the prediction of meat yield when EUROP conformation score was included in the prediction models have been previously reported by Safari *et al*. (2001). In that study, a maximum increase in accuracy of 57% was found when the percentage of saleable meat yield (SMY) was predicted using CCW including EUROP conformation scores and a measure of fatness rather than CCW only. The EUROP system has also recently been investigated for its ability to predict the percentage of lean meat in lamb carcasses (Johansen *et al.* 2006). In that study, CCW and EUROP conformation and fat class were used as predictors for lean meat percentage, explaining 41% of the variation in the trait. A higher variation was found in the present study for the prediction of total meat yield of the carcass (99%). However, this high variation was expected assuming the strong dependency between the predictor used in the model (CCW) and the predicted traits (weight of carcass primal cuts).

Table 2.3 Coefficient of determination (R^2) and residual root mean squared error (RMSE) for the prediction of dissected primal meat yields (kg) using cold carcass weight (CCW) in both prediction equation: MLC-CF (conformation and fat) scores and VIA estimates of primal carcass joints (VIA-primals).

	LEG[¥]		CHUMP		LOIN		BREAST		SHOULDER		Total primals	
Factors in model	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE
MLC-CF	0.31	0.708	0.51	0.122	0.42	0.474	0.47	0.302	0.39	0.837	0.41	2.284
CCW + MLC-CF	0.94	0.213	0.92	0.048	0.89	0.206	0.82	0.176	0.95	0.233	0.99	0.292
CCW + MLC-CF + sd[†] + SEX[§]	0.94[§]	0.211	0.93[†]	0.047	0.91[†]	0.19	0.86[†§]	0.155	0.96[†]	0.208	0.99[†§]	0.262
VIA-primals	0.97	0.155	0.94	0.042	0.89	0.204	0.86	0.156	0.96	0.222	0.99	0.254
VIA-primals + sd[†]+ SEX[§]	0.97	0.155	0.94	0.042	0.91[†]	0.191	0.88[†]	0.147	0.96[†§]	0.202	0.99[†]	0.237

[†] Significant effect ($P \leq 0.05$) of slaughter day (sd) in the model

[§] Significant effect ($P \leq 0.05$) of sex in the model

[¥]Primal joints in kilograms

The prediction equations including MLC-CF scores adjusted by CCW (model 1), was then compared to the prediction equations using individual VIA-primals (model 2) in their ability to predict primals meat yield. Higher accuracies were found when VIA carcass information was used in the prediction equations to estimate primal joints. Higher accuracies in the prediction of primal joints LEG, CHUMP, BREAST and SHOULDER of 3%, 2%, 5% and 1%, respectively were achieved using the VIA information compared to the models including MLC-CF scores. The accuracies of the estimation of primal LOIN (R^2 = 0.89) and total primals (R^2 = 0.99) were the same using VIA or MLC-CF information. The precision substantially increased when using VIA instead of MLC-CF scores as indicated by a reduction in RMSE of 27%, 13%, 1%, 11%, 5% and 13% for estimation of weights of LEG, CHUMP, LOIN, BREAST, SHOULDER and total primals, respectively. Stanford *et al*. (1998) also reported a better prediction ability for SMY when using a VIA system rather than when using the system based on tissue depth at the GR site (thickness over the 12th rib, 11 cm from the midline) and subjective conformation scores. Other work, undertaken by Brady *et al.* (2003), corroborates these results with higher accuracy found in the prediction of yields of wholesale cuts using a Lamb Vision System (LVS). Using hot carcass weight together with tissue depth at the GR site or carcass measures from a VIA system (VIAScan®), Hopkins *et al.* (2004) also reported much higher levels of accuracy and precision in the prediction of lean meat yield (percentage) when using the VIA system. The results from the present study support the findings from other authors on the ability of the VIA systems to predict meat yield of various primal cuts. However, further analysis based on the ability of the VIA system to predict meat yield and lean meat yield in percentage would increase the value of future studies in assessing the benefits of the use of this automatic technology in abattoirs. Additionally, the benefits from using computer tomography measures of carcass composition (proportions of lean, fat and bone) as a reference method to calibrate the VIA system have yet to be investigated. Computer tomography (CT) has been reported as a very accurate method to assess carcass composition (Young *et al.* 1996; Lambe *et al.* 2003; Kvame *et al.* 2004; Macfarlane *et al.* 2006). This method offers a standardized, and more accurate and reliable way of estimating lean, fat and bone of the lamb carcasses than the carcass dissection

(Kongsro *et al.* 2008) and has the potential to be used as a reference against which VIA could be calibrated. One of the main concerns over the use of VIA systems is that there is not a standardized butchery protocol. Consequently, the VIA system would have to be individually calibrated for each of the slaughter plants if they use different specifications. The use of CT estimates of carcass composition as a reference method could overcome the difficulties of standardizing the industry practice on dressing specifications, while providing values of carcass quality based on proportions of lean, fat and bone.

2.3.3 Influence of slaughter day and sex effect on the estimation of primal carcass cuts

To test if predictions based on VIA traits or MLC-CF classification differ in their sensitivity to environmental variation, sex and slaughter day were used as examples for environmental factors, and their effects on both sets of predictions were evaluated. Although measures were taken (i.e. light intensity, time period between slaughter and evaluation) to reduce the environmental variation during the subjective and automatic evaluation of carcass quality, it was most likely that factors such as temperature, day of the week and time of the day might have influenced the evaluation. Therefore, to account for how much of this environmental variation is accounted for in the evaluation the influence of the sex and slaughter day factors on the accuracy and precision of the estimation of primal joints and total primals using MLC-CF and VIA carcass information is presented in Table 2.3. Adjusting prediction from MLC-CF carcass information and CCW for sex and slaughter day resulted in an improvement of the accuracy for primals CHUMP, LOIN, BREAST and SHOULDER of 1%, 2%, 5% and 1%, respectively, and a much higher increase in precision (reduction in RMSE by 2%, 8%, 12% and 11, respectively).

Accuracy of prediction using VIA carcass information did not improve after adjustment for sex and slaughter day for the primals LEG, CHUMP, SHOULDER and total primals but improved by 2% for LOIN and BREAST primals. Moreover, the precision of estimation of LEG and CHUMP by VIA was not improved due to adjustment for sex and slaughter day, whereas improvements of 6%, 6%, 9%, and 7% were obtained for LOIN, BREAST, SHOULDER and total primals, respectively. These results indicate that VIA prediction of carcass cuts were less affected by slaughter day and sex than those using MLC-CF scores. This suggests that predictions using VIA are less sensitive to environmental variations (represented by different slaughter days and the influence of sex) than those based on MLC-CF scores.

After adjustment for sex and slaughter day, the prediction model based on VIA information achieved a higher precision in the estimation of primals LEG, CHUMP, BREAST, SHOULDER and total primals of 27%, 11%, 5%, 3% and 10% rather than a model using MLC-CF information (Table 2.3). One exception was the estimation of primal LOIN, for which the precision was similar using VIA or MLC-CF information. These results are consistent with those reported by Horgan *et al.* (1995), who found higher accuracies when estimating weights of carcass cuts (62% to 77%) and higher precisions using linear carcass measurements from automatic digital image analysis than when using subjective MLC-CF scores.

The observation of higher accuracy and precision of VIA systems in predicting total primals in comparison with other more subjective technologies is consistent with other British, Australian and American studies (Horgan *et al.* 1995; Stanford *et al.* 1998; Brady *et al.* 2003). The accuracy and precision of the VIA system used in this study for the estimates of primal joints was found to be slightly higher than those from the results presented by Brady *et al.* (2003) for the evaluation of a lamb vision system as a predictor of boneless and bone-in weight of cuts. Accuracy and precision for primal cuts, reported by Brady *et al.* (2003), showed R^2 ranging from 0.65 to 0.86 for boneless weights of rack and bone-in weights of shoulder and RMSE values ranging from 0.35 to 0.50 for bone-in weights of rack and shoulder, respectively.

The sex effect was significant for most predictions based on MLC carcass information (Table 2.3). In contrast, using VIA carcass information, the sex effect was not significant in most of the traits except for primals SHOULDER at a significance level of P < 0.01 (Table 2.3). In agreement with previous studies (Jones *et al.* 1992; Brady *et al.* 2003), the variable CCW was significant for all traits analyzed and explained: 84%, 88%, 85%, 78% and 94% of the total variation for primal joints LEG, CHUMP, LOIN, BREAST and SHOULDER, respectively.

2.3.4 Stability of trimmed primal cuts using MLC and VIA carcass information

Prediction models using MLC-CF or VIA carcass information adjusted only for CCW (models 1 and 2) were analyzed for their ability to predict primal joints and total primals using the full 'leave-one-out' cross validation approach implemented in the PLS procedure. Table 2.4 presents the cross-validation results using MLC-CF or VIA information adjusted only for CCW (model 1 *vs.* model 2) because in a commercial perspective it is difficult to adjust for sex (and impossible to adjust for slaughter day). The criteria of root mean squared errors of the prediction (RMSECV) were used to compare the predictability of the models. Using VIA instead of MLC-CF information resulted in a higher stability, as indicated by a reduction in RMSECV of 28%, 11%, 2%, 12%, 6% and 14% for LEG, CHUMP, LOIN, BREAST, SHOULDER and total primals, respectively. Johansen *et al.* (2006) reported a prediction error (RMSECV) of 0.307 for the prediction of lean meat in percentage using CCW and EUROP conformation. This RMSECV falls in the range of prediction errors found in the present study for the prediction of primal joints using CCW and MLC-CF scores.

Table 2.4 Root mean squared errors from cross-validation (RMSECV) of carcass joints and total primals using MLC-CF[†] or VIA[§] carcass information

	MLC			VIA		
Primals	R^2	RMSECV	RMSECV/SD	R^2	RMSECV	RMSECV/SD
LEG	94	0.257	0.305	97	0.184	0.218
CHUMP	92	0.284	1.651	94	0.253	1.471
LOIN	89	0.337	0.537	89	0.330	0.526
BREAST	82	0.433	1.054	86	0.382	0.929
SHOULDER	95	0.222	0.209	96	0.209	0.197
TOTAL	99	0.101	0.034	99	0.087	0.030

[†] Model 1(adjusted for CCW)

[§] Model 2

These results showed that VIA information is able to predict meat yield of primals more accurately than MLC-CF scores. This lower stability using MLC-CF scores is consistent with its higher sensitivity to environmental effects.

2.4 Conclusions

Video image analysis (VSS2000) technology provides a fast and non-invasive method to predict weights of primal joints: LEG, CHUMP, LOIN, BREAST, SHOULDER and total primals meat yield, and shows an accuracy and precision that are at least as high, or even higher than when using MLC-CF scores. The adjustment for the effects of CCW, sex and slaughter day increased the accuracy and precision of estimation using VIA or MLC-CF scores. This indicates that estimations based on MLC-CF scores were more sensitive to environmental effects than those based on the VIA system. Using VIA rather than the subjective MLC-CF scores improved the estimation of total primals and most primal joints. Commercially, VIA would provide the UK lamb industry with a greater consistency in the estimations of meat yield from primal joints than the present MLC scoring system.

2.5 Implications

At present, in the European Union (EU) there is no requirement for the classification of carcass quality in the lamb industry. Lamb carcass classification has been based on the EUROP carcass grading for conformation and fatness which was developed in the early 1970s for the beef industry. However, the new carcass dressing specification which has recently been accepted for the EU to increase consistency in the way cattle are measured, trimmed and processed in abattoirs might serve as a precedent to also standardize how lamb carcass are trimmed and process in abattoirs. These changes in the cattle and sheep industry could provide a base for the incorporation of automated technologies to objectively assess carcass value. Therefore, the prediction of primal meat yields as reported in the present study could be of high interest to the UK sheep industry. The use of this technology could facilitate the development of an alternative marketing system in the UK through the development of payment criteria based on carcass meat yield likely to be in place in the near future. Additionally, precise estimation of carcass quality by VIA has high potential to be used efficiently in genetic improvement programmes.

Chapter 3

Genetic parameters for carcass composition and performance data in crossbred lambs measured by Video Image Analysis

Abstract

A total of 7074 crossbred lambs, produced by mating crossbred Mule ewes with terminal sire rams, were used in this study. Amongst these, 630 were scanned using Video Image Analysis (VIA) to estimate carcass quality traits. Genetic parameters for Average Daily Gain (ADG), scanning live weight (SW), ultrasonic measures of muscle (UMD) and fat (UFD) depths, Cold Carcass Weight (CCW) and VIA measurements of primal carcass joint weights (LEG, CHUMP, LOIN, BREAST and SHOULDER) were estimated using multivariate animal models. Additionally, VIA traits were evaluated under a repeatability model, considering the primal joints as repeated measures of the same trait. Direct heritability estimates were low to moderate (0.08 – 0.26) for VIA measurements of primal joints. Repeatability estimates for VIA traits were high (> 0.90). Moderate to high heritability estimates (0.25 – 0.55) were found for performance traits (ADG, SW, UMD and UFD) and CCW. Genetic correlations between VIA traits and ADG were strong (0.75 – 0.93). Most of the VIA traits were highly correlated to SW (0.60 – 0.97). UFD was significantly negatively correlated with UMD (-0.22), ADG (-0.18) and CCW (-0.18). The results of this study suggest that selection on performance and carcass traits, measured by VIA, could possibly improve primal meat yield of carcass cuts without increasing the overall carcass fatness. High repeatability estimates of VIA traits and moderate heritabilities of the most valuable carcass joints suggest that including VIA information in breeding programmes would be useful in order to improve carcass quality.

3.1 Introduction

One of the main objectives of sheep breeding programmes in the UK is to improve carcass characteristics within the framework of a stratified system (Dewar-Durie 2000), which utilizes a variety of breeds suited to the different climate and landscape (upland, lowland) niches to produce slaughter lambs (Simm *et al.* 2001). The majority of these slaughter lambs result from crossing terminal sire rams (for example, Texel, Charollais and Suffolk) with Scottish Mule (Bluefaced Leicester x Scottish Blackface), North of England Mule (Bluefaced Leicester x Swaledale) or Welsh Mule (Bluefaced Leicester x Welsh Hardy Speckled Face or Beulah Speckled Face) ewes. Over the past 15 years, genetic selection for improved carcass composition in terminal sire breeds using the Lean Growth Index has shown positive effects on the carcass quality of their crossbred progeny (Simm *et al.* 2001).

Accurate measures of carcass characteristics in terminal sire breeds are possible using ultrasound and computer tomography (CT). These technologies are used in the UK (Simm and Dingwall 1989; Jones *et al.* 2002; Jones *et al.* 2004; Karamichou *et al.* 2006; Macfarlane *et al.* 2006; Wolf *et al.* 2006; Navajas *et al.* 2007) and elsewhere (Kvame *et al.* 2004; Silva *et al.* 2005; Teixeira *et al.* 2006; Hopkins *et al.* 2007) to predict *in vivo* carcass merit. They are well understood and have been proven to be valuable tools for genetic improvement of carcass traits. Furthermore, direct measures of carcass traits on crossbred lambs sired by terminal sire breeds would improve the accuracy of the genetic evaluation of sires in these breeds, and thus increase rates of genetic improvement for carcass characteristics. Integration of carcass information in livestock selection programmes has been modeled, and results show that it is an effective way of improving carcass quality (Jones *et al.* 1999; Crews *et al.* 2003; van Wijk *et al.* 2005). However, the incorporation of this information into breeding programmes is currently compromised, firstly by limitations on how individual carcass data can be collected and secondly by the type of measurements used to assess carcass quality. Carcass dissection provides accurate measures of lean meat, fat and bone ratios in the whole carcass and in the joints; however, the routine collection of these data within abattoirs operating commercially is not time- or cost-effective. The current carcass grading system used to assess the carcass value in the UK is based on MLC carcass classification for conformation and fatness, and provides a fast and cost-effective way of assessing carcass value. However, carcass conformation is positively correlated with measures of fatness both genetically and phenotypically (Lewis *et al.* 1996; Conington *et al.* 1998; Jones *et al.* 1999; Moreno *et al.* 2001; Karamichou *et al.* 2006) and it is poorly associated with carcass composition (Kempster *et al.* 1982). Therefore, current measures of conformation and fatness available in abattoirs have a restricted role in selection programmes that aim to breed for reduced fatness and increased lean tissue growth rate.

An innovative technology based on video image analysis (VIA), that can objectively and accurately predict lamb carcass composition (Horgan *et al.* 1995; Stanford *et al.* 1998; Brady *et al.* 2003), is being evaluated with a view to introducing it into the UK lamb abattoirs. VIA is a fast and non-invasive method of predicting primal meat yields of lamb carcass joints with high accuracy and precision (Rius-Vilarrasa *et al.* 2009b, Chapter 2). However, there are no known estimates of either genetic parameters for VIA measurements of lamb carcasses or their associations with live animal performance data in commercial lambs.

Predictions of repeatabilities and heritabilities of VIA traits and their genetic correlations with traits already used in breeding programmes are crucial to identify the value of this new information for genetic improvement programmes. Therefore, the aims of the present study were to estimate: (1) the repeatability of VIA carcass measurements and (2) genetic parameters for VIA and performance traits in a terminal sire crossbred lamb population.

3.2 Materials and methods

3.2.1 Animal resource

Over a six-year period a total of 7047 crossbred lambs were produced by mating crossbred Mule ewes with terminal sire rams of high and low genetic merit for Lean Growth Index. The lambs in this study were reared at research farms in England (Rosemaund), Scotland (Edinburgh) and Wales (Aberystwyth) where the lambs' ancestry, birth weight and sex were recorded. Within 48 hours of lambing, the Mule ewes and their lambs were moved to pasture. Litters were kept as singles or twins, and lambs from larger litters were fostered to another ewe when possible. If fostering was not possible, lambs were reared artificially and excluded from this study. Most of the lambs were reared as twins (80%) with the remainder reared as singles. Ewes suckling twin lambs were grazed separately from those with singletons and offered supplementary feeding as required. The production of the Mule ewes used as well as the selection of the terminal sire rams is described in more detail in earlier studies (Jones *et al.* 1999; Simm *et al.* 2001; Van Heelsum *et al.* 2003; Van Heelsum *et al.* 2006).

Data from 6417 lambs born between 2000 and 2003 were available from a previous study. These lambs were sired by 95 rams and born out of 1691 ewes within 3923 litters. The last mating (2006) produced 630 crossbred lambs; these lambs were sired by 18 rams and were born out of 385 ewes within 385 litters. For this sub-group, ultrasonic measurements of fat and muscle depth at finished condition were replaced by VIA measures on the carcass, and these were used in this study to estimate the genetic parameters for VIA traits (Table 3.1). Ultrasound scanning was performed, on the 6417 lambs born between 2000 and 2003, using a Dynamic Imaging Concept MLV ultrasonic scanner with a 3.5 MHz transducer, at the 3rd lumbar vertebra. Muscle depth (UMD) was measured vertically at the deepest point of the eye-muscle (*musculus longissimus dorsi*). Three individual subcutaneous fat depth measurements were taken over the *longissimus dorsi* muscle, moving 1.88 cm laterally between the vertical and transverse processes of the vertebra, from which the average fat depth was calculated (UFD). Ultrasonic data on the dataset of 6417 lambs was used in this study to estimate the genetic parameters of UMD and UFD and average daily gain (ADG) and live weight at ultrasound scanning (SW) at finishing condition. Cold carcass weight (CCW) was also included in the analysis. These two groups were genetically linked because the 630 lambs evaluated using VIA were from a sub-population of the ewes generating the performance dataset, with 11 common sires between the two data sub-sets (Table 3.1). Additional pedigree information was available, and the complete pedigree comprised 9261 animals after checking for inconsistencies with the software RELAX2 (Strandén and Vuori 2006).

Table 3.1 Data characteristics of video image analysis (VIA) and performance measurements

	VIA	Performance
Item		
Total number of animals: 7047		
Animals with records	630	6417
Number of sires	18	95
Common sires in both data sets	11	11
Number of offspring from common sires	409	1401
Number of dams	385	1691
Offspring per dam		
Scottish Mule	304	3087
Welsh Mule	326	3402

3.2.2 Carcass measurements on crossbred lambs

The 630 lambs born in 2006 were slaughtered at finishing condition (estimated fat class 3L; average age 5 months) under commercial conditions at Welsh Country

Foods (WCF) abattoir in Gaerwen (Wales). Lamb carcasses were presented in a standardized position with the legs spread apart (gambrel) and shoulders un-banded for VIA scanning of back and side views of the carcasses. All lamb carcasses were scanned twice to allow estimates of repeatability. Each batch of five or ten carcasses was scanned once and immediately after this first scan a second scan was taken. The two scans were taken over a time span of approximately five to ten minutes. Lambs were redirected from the main slaughter line to a secondary line specifically designed to steer the carcasses to a VIA station for scanning (VSS2000, E+V Technology GmbH, http://www.eplusv.de/). The VIA carcass assessment unit of VSS2000 consists of: (i) stationary image capture devices (cameras 0 and 1) with standardized lighting; (ii) image processing and analyzing software (VSS2000); (iii) a metal structure and chain to move carcasses through the VIA station. The secondary slaughter chain was adjusted to the same speed as the actual slaughter line to reproduce the online conditions in the abattoir (800 carcasses/h).

The VIA system measures dimensional characteristics of the carcass as well as colour variation at selected positions. The software captures the image and divides the carcass into different regions. These serve as the basis for making a series of carcass measurements, which are then used as system output variables that describe the shape and size of the carcass, and the relative proportions of fat and lean tissue. Carcass shape and colour measurements obtained by image analysis and the CCW (kg) were used by the VIA manufacturer (E+V Technology GmbH) to estimate measures of different primal carcass joints weights (kg) in the LEG, CHUMP, LOIN, BREAST and SHOULDER, referred to from here as VIA traits. The estimates of these primals joints were based on dissection data collected under specific butchery specifications used in Welsh Country Foods. The dissection procedure provided pre-retail level primals with external (subcutaneous) fat trimmed to a maximum of 6 mm at any point on the cut to obtain the primal cuts.

LEG joints were removed by cutting and sawing in approximately 12 mm a straight line below the aichbone through the base of the tail. The knuckle was removed from the tibia (below the calcaneal tuber) and the aichbone was then removed from the legs. The CHUMP joints were separated into boneless chump by cutting through the hipbone (ischium and ilium) and the point end of the chump. The left and right saddles were separated into LOIN and BREAST joints by cutting a parallel cut to the back bone from a point approximately twice the length of the eye muscle at the anterior end (best end of neck) of the loin. The loin joints were removed by sheet boning the bones that are normally attached to the breast. Half the length of the rib bones was removed by cutting to a maximum of 35 mm from the chine bone. The shoulder flap (point of the breast) was squared off and separated into lean trim. The back strap (ligamentum nuchae) and the knuckle ends (50 mm above the joint at the lower end of the radius and ulna) were removed from the SHOULDER joint (there was no subcutaneous fat removed from shoulders).

The performance data included 6417 records of crossbred lambs, which were collected over the initial years of the trial. From the age of approximately 10 weeks, the lambs were assessed every two weeks for the achievement of finished condition (3L), which was on average at 6 months of age. Pre-slaughter measurements taken on the finishing lambs were UMD, UFD and SW. Average daily gain (ADG) was defined as the difference between finishing weight and birth weight divided by days of age at slaughter. UMD was measured at the deepest point of the eye-muscle (*m. longissimus lumborum*), at the third lumbar vertebra. UFD was measured at the same position and 1 and 2 cm lateral to the first position. The average of these three fat measurements was used in the genetic analysis. Once reaching finishing condition, the lambs were slaughtered under commercial conditions at either Hamer International in Wales or ABP Ltd. abattoirs in Scotland. The cold carcass weight (CCW) was recorded 24h post-slaughter. Table 3.2 presents a description of traits used in this study.

Table 3.2 Description of traits measured on lambs at finishing condition and on lamb carcasses used in the analysis of genetic parameters

Abbreviation	Description
LEG	VIA estimate of meat yield from the leg (kg)
CHUMP	VIA estimate of meat yield from the chump (kg)
LOIN	VIA estimate of meat yield from the loin (kg)
BREAST	VIA estimate of meat yield from the breast (kg)
SHOULDER	VIA estimate of meat yield from the shoulder (kg)
ADG	Average daily gain (g)
SW[†]	Scanning weight (kg)
UMD[†]	Ultrasonic muscle depth at the 3rd lumbar position (mm)
UFD[†]	Ultrasonic fat depth at the 3rd lumbar position (mm)
CCW	Cold carcass weight (kg)

[†]Measured at finishing condition

3.2.3 Statistical analysis

Preliminary analyses were performed to investigate the non-genetic factors influencing the traits using the GLM procedure within SAS (SAS Institute Inc., Cary, NC, USA). The fixed effects included in the analysis were: batch (year of birth, sex and farm), sire breed (3 classes: Texel, Charollais or Suffolk), age of the dam (8 classes: 2 to 8 and >8), and birth-rearing type (6 classes: (1) born single reared as single, (2) born single reared as twin, (3) born twin reared as single, (4) born twin reared as twin, (5) born triplet reared as single, (6) born triplet reared as twin). All traits were adjusted by age at slaughter included as either a linear or negative exponential covariable.

Restricted Maximum Likelihood (REML) methods were then used to estimate (co)variance components using an animal model as implemented in the ASReml program (Gilmour *et al.* 2002). Firstly, univariate analyses were performed to evaluate the significance of different random factors in the model. The basic model included only the direct additive genetic effect. The maternal additive genetic effect, maternal permanent environmental effect and common environmental effect were added subsequently. Higher likelihood values were obtained when more parameters were included in the model, so more variance was explained by the model. To evaluate the significance of a random effect in the model, a likelihood ratio test was performed, that compared reduced and full models, with one degree of freedom, to a critical value from chi-square distribution.

Following the univariate analysis, multivariate analyses were performed using the most appropriate model for each trait as described in Table 3.3. The animal models used to estimate heritability and genotypic and phenotypic correlations for VIA and performance traits were as follows:

$$Y_{ijl} = BH_i + DA_j + b_1(AS_{ijl}) + a_l + e_{ijl}, \qquad [1]$$

$$Y_{ijlm} = BH_i + DA_j + b_1(AS_{ijlm}) + a_l + pe_m + e_{ijlm}, \qquad [2]$$

$$Y_{ijklq} = BH_i + T_j + BR_k + b_1(AS_{ijklq}) + a_l + ce_q + e_{ijklq}, \qquad [3]$$

$$Y_{ijlmn} = BH_i + T_j + b_1(-\exp AS_{ijlmn}) + a_l + m_m + ce_n + e_{ijlmn}, \qquad [4]$$

with cov (a,m) = 0

where $\boldsymbol{Y_{ijlmn}}$ is the record for animal *l* with dam *m* and fixed effects; $\boldsymbol{BH_i}$ the combined fixed effect of *i*th year of birth, sex and farm (batch) fitted for all the traits; $\boldsymbol{DA_j}$ the effect of *j*th dam age included only in the models for VIA traits (model 1) and the repeatability model (model 2); $\boldsymbol{T_j}$ the effect of *j*th birth-rearing type included in model 3 for SW, UMD, UFD and CCW and model 4 for ADG; $\boldsymbol{BR_k}$ the effect of *k*th breed included only in model 3 for performance traits, UMD and UFD; ***AS*** age at slaughter as a covariate with $\boldsymbol{b_1}$ as regression coefficient of ***Y*** on slaughter age. The relationship between ADG and day of slaughter was observed to have exponential decay, so that animals with higher ADG reached finish condition at an earlier stage where older lambs showed lower ADG. Therefore to accommodate a linear relationship between ADG and slaughter day the negative exponential of this effect was included in model 4. Of the random effects, $\boldsymbol{a_l}$ was the direct additive effect of the animal; $\boldsymbol{m_m}$ the maternal genetic effect; $\boldsymbol{pe_m}$ the permanent environmental effect and $\boldsymbol{ce_q}$ the common environmental (litter) effect.

Table 3.3 Factors included in the models for the estimation of genetic parameters for VIA and performance traits

	VIA traits	ADG	SW	UMD	UFD	CCW
Fixed effects						
Batch	✓	✓	✓	✓	✓	✓
Breed				✓	✓	
Dam age	✓					
Birth rear type		✓	✓	✓	✓	✓
Random effects						
Litter		✓	✓	✓	✓	✓
Dam		✓				
Animal	✓	✓	✓	✓	✓	✓
Covariates						
Age at slaughter	✓		✓	✓	✓	✓
1/x, x=Age at slaughter		✓				

3.3 Results

3.3.1 Summary statistics

Means and standard deviations for VIA and ultrasonic carcass measurements are given in

Table 3.4. VIA predicted carcass joint weights, LEG, CHUMP, LOIN, BREAST and SHOULDER, comprise 19%, 5%, 8%, 9% and 22% respectively of total cold carcass weight. ADG and UFD were the most variable traits with a coefficient of variation of

30% and 31% respectively, compared to a coefficient of variation of 9% for UMD. Carcass joints assessed by VIA showed moderate and similar coefficients of variation with values of 12%, 12%, 20%, 18% and 12% for LEG, CHUMP, LOIN, BREAST and SHOULDER, respectively.

Table 3.4 Means, standard deviations (SD) and ranges of primal meat yields predicted by VIA and of performance traits as well as the coefficient of variation (CV) for these traits measured on crossbred lambs and lamb carcasses.

	Mean	SD	Minimum	Maximum	CV (%)
VIA traits (kg)					
Leg	3.65	0.425	2.55	5.52	11.6
Chump	0.88	0.108	0.55	1.36	12.2
Loin	1.49	0.304	0.69	2.97	20.4
Breast	1.76	0.311	1.09	3.24	17.7
Shoulder	4.17	0.510	2.73	6.47	12.2
CCW[†]	18.80	2.419	13.00	29.50	12.8
Performance traits					
ADG (g)	0.23	0.068	0.08	0.47	29.9
SW (kg)	41.82	4.646	27.20	62.00	11.1
UMD (mm)	24.76	2.140	17.00	36.20	8.90
UFD (mm)	3.98	1.251	1.13	11.93	31.4
CCW[§] (kg)	19.30	2.199	11.31	30.35	11.4

[†]Measured on 630 lamb carcasses

[§]Measured on 7074 lamb carcasses

3.3.2 Repeatability analysis for VIA carcass traits

Estimates of the phenotypic correlation from repeated VIA records of joint weights (LEG, CHUMP, LOIN, BREAST and SHOULDER) together with estimated variance components are presented in Table 3.5. Lamb carcasses were scanned in batches of five or ten at a time. In each batch, the carcasses were put through the VIA station so that the second scan was taken always after all the carcass had been scanned once. This methodology allowed for a short time period between the first and the second image being taken and therefore high repeatability estimates (r) were found, ranging from 0.90 (CHUMP) to 0.99 (BREAST). Estimates of direct additive variance (σ_a^2) varied from 0.001 for CHUMP to 0.024 for LEG. Substantially higher estimates were found for the random permanent environmental (σ_{pe}^2) effect, with variances ranging from 0.008 for CHUMP to 0.180 for SHOULDER, contributing 80% (CHUMP) and 89% (SHOULDER) to the total phenotypic variance (σ_p^2). Residual variances (σ_e^2) were small for all VIA traits.

Table 3.5 Phenotypic (σ_p^2), additive (σ_a^2), permanent environment (σ_{pe}^2) and residual variances (σ_e^2) with repeatability (r) estimates for VIA traits measured on crossbred lamb carcasses

Traits	σ_p^2	σ_a^2	σ_{pe}^2	σ_e^2	r[†]
LEG	0.137	0.024	0.111	0.002	0.98
CHUMP	0.010	0.001	0.008	0.001	0.90
LOIN	0.079	0.018	0.057	0.004	0.95
BREAST	0.070	0.015	0.054	0.002	0.99
SHOULDER	0.203	0.018	0.180	0.006	0.97

[†]repeatability ($\sigma_a^2 + \sigma_{pe}^2 / \sigma_p^2$) with standard errors < 0.006.

3.3.3 Genetic parameters

Heritability estimates, genetic and phenotypic correlations, (with standard errors), from the multivariate analyses of VIA and the performance traits are presented in Table 3.6. Moderate heritability estimates were obtained for VIA carcass traits of

0.20, 0.26 and 0.23 for LEG, LOIN and BREAST, respectively, which, based on their corresponding standard errors, were significantly different from zero. Heritability estimates for CHUMP and SHOULDER were low (0.07 and 0.08 respectively), and not significantly different from zero.

Besides genetic parameters of the VIA traits, the heritabilities for performance traits were estimated in a multivariate analysis, and these are also as presented in Table 3.6. The heritability for ADG was moderate (0.25), with a small standard error (±0.04). A similar heritability (0.28) was obtained for SW, although this estimate was not significantly different from zero, as shown by the high standard error (±0.15). A high heritability of 0.55 was estimated for CCW, with a low standard error of ±0.04. Ultrasonic traits had higher heritability estimates than growth traits.

Estimates of genetic correlations among and between VIA carcass traits, performance traits and CCW are presented in Table 3.6. The genetic correlations among VIA traits were moderate to high, ranging from 0.39 between CHUMP and SHOULDER to 0.93 between LEG and BREAST or SHOULDER. The VIA estimate of LEG weight was found to be highly genetically correlated with the other VIA carcass traits (CHUMP 0.83, LOIN 0.90, BREAST 0.93, and SHOULDER 0.93). CHUMP showed the lowest genetic correlations to the other VIA carcass traits (LEG 0.83, LOIN 0.81, BREAST 0.63, and SHOULDER 0.39). The genetic correlations among performance traits varied from -0.18 between CCW or ADG and UFD to 0.95 between ADG and SW. A negative genetic correlation of -0.22 was found between UMD and UFD. Genetic correlations between UFD and ADG, SW and CCW were all small and negative (ADG -0.18, SW -0.01, CCW -0.18). A low positive genetic correlation was found between UMD with ADG (0.19). The highest genetic correlations were found between ADG and SW (0.95) and ADG and CCW (0.87). The genetic correlations between VIA traits and growth traits (ADG, SW and CCW) were moderate to high, ranging from 0.60 between CHUMP and SW to 0.97 between LEG and SW, except for a low genetic correlation between SHOULDER and SW of 0.28. VIA traits LEG and BREAST showed consistently high genetic correlation with growth traits. Genetic correlations between VIA traits and ultrasonic traits were generally low and associated with large standard errors, so that all estimates were not significantly different from zero.

Estimates of phenotypic correlations were robust, with standard errors less than 0.02. The phenotypic correlations among VIA traits were high, ranging from 0.81 to 0.94, and generally of the same magnitude as the corresponding genetic correlations, except for between CHUMP, BREAST and SHOULDER, for which the phenotypic correlations were higher than the genetic correlations. Among growth and ultrasonic traits, phenotypic correlations varied from 0.04 between UMD and UFD to 0.92 between ADG and SW. The phenotypic correlations of UFD with VIA or growth traits were all close to zero. The phenotypic correlations between SW and LOIN (0.19) and SHOULDER (0.12) were low, while the other correlations between SW and VIA were moderate to high.

Table 3.6 Estimates of heritabilities, phenotypic and genetic correlations (standard errors) for VIA based predictions of kilograms of primal cuts and performance traits in crossbred lambs and lamb carcasses[†]

Trait	LEG	CHUMP	LOIN	BREAST	SHOULDER	ADG	SW	UMD	UFD	CCW
LEG	**0.20 (0.09)**	0.84	0.86	0.94	0.90	0.25	0.72	0.17	-0.02	0.35
CHUMP	0.83 (0.16)	**0.07 (0.07)**	0.85	0.81	0.85	0.19	0.56	0.23	0.07	0.63
LOIN	0.90 (0.07)	0.81 (0.16)	**0.26 (0.10)**	0.82	0.85	0.23	0.19	0.20	0.17	0.24
BREAST	0.93 (0.05)	0.63 (0.28)	0.79 (0.12)	**0.23 (0.10)**	0.86	0.23	0.72	0.22	-0.01	0.60
SHOULDER	0.93 (0.09)	0.39 (0.57)	0.83 (0.14)	0.91 (0.12)	**0.08 (0.06)**	0.21	0.12	0.32	0.02	0.27
ADG	0.93 (0.13)	0.83 (0.23)	0.75 (0.15)	0.81 (0.15)	0.85 (0.17)	**0.25 (0.04)**	0.92	0.20	0.11	0.78
SW	0.97 (0.07)	0.60 (0.19)	0.63 (0.16)	0.93 (0.07)	0.28 (0.11)	0.95 (0.01)	**0.28 (0.15)**	0.34	0.26	0.83
UMD	0.11 (0.16)	0.24 (0.21)	0.13 (0.18)	0.22 (0.15)	0.10 (0.31)	0.19 (0.08)	0.30 (0.07)	**0.35 (0.03)**	0.04	0.19
UFD	-0.07 (0.18)	0.05 (0.27)	0.33 (0.21)	-0.02 (0.17)	0.67 (0.38)	-0.18 (0.09)	-0.01 (0.08)	-0.22 (0.08)	**0.35 (0.04)**	0.07
CCW	0.62 (0.20)	0.72 (0.17)	0.70 (0.17)	0.70 (0.17)	0.60 (0.23)	0.87 (0.02)	0.87 (0.02)	0.12 (0.08)	-0.18 (0.07)	**0.55 (0.04)**

[†]Estimated heritabilities (on diagonal), phenotypic (above diagonal) and genetic correlations (below diagonal). Standard errors of phenotypic correlations are less than 0.02.

3.4 Discussion

3.4.1 Repeatability of VIA traits

To judge the reliability of a new carcass evaluation system such as VIA, it is important to estimate the accuracy of the system by the repeatability of measures as defined by Falconer and Mackay (1996). The VIA system showed low residual variances which contributed to the very high repeatability estimates for predicted VIA traits, LEG, CHUMP, LOIN, BREAST and SHOULDER (average 0.96). A possible reason for these low residual variances and high repeatability estimates could be the way carcasses were scanned. Repeated measurements were taken at each batch of five or ten lamb carcasses. After the whole batch was scanned once, a consecutive second scan was taken. Carcasses needed to be manually placed in the scanning area. Therefore to reduce the environmental variation in the estimates, the same person positioned all the lamb carcass of this study in front of the VIA system.

These repeatability estimates were obtained off the main slaughter line, and somewhat lower repeatability estimates for VIA traits might occur for a fully automated VIA scanning system integrated into the main slaughter line. Indeed, if the VIA system is integrated to the main slaughter line, carcasses might be presented to the VIA system with some more movement than in the experimental situation described in this study, which could reduce the level of repeatability.

Accounting for environmental factors only, Steiner *et al.* (2003a) reported less variability in the estimates of *longissimus* muscle area (LMA) in beef when using a VIA system than when using the subjective techniques for measuring LMA. A similar approach by Johansen *et al*. (2006) investigated the repeatability of senior assessors for the evaluation of conformation and fat scores of the system in Norway and found moderate to high repeatability estimates for conformation and fat scores. Studies on other automatic technologies used to measure carcass characteristics, such as ultrasound scanning, have shown high repeatability estimates ranging from 0.60 to

0.99 (Lauridsen 1998; Puntila *et al.* 2002). There are sufficient references supporting automatic technology as a measure of carcass quality with a high level of consistency, based on high repeatability estimates. The results of this study corroborate these findings, showing that when using a VIA system it could be obtained robust measure of carcass quality in abattoirs. Repeated measurements (permanent environmental effects) were only taken in this experiment to evaluate the repeatability of the VIA system and they would not be available for VIA installed online in abattoirs. Consequently, to estimate the heritabilities of VIA traits, only the direct genetic effect of the animal was fitted in the model as a random effect.

3.4.2 Heritability estimates

To the best of our knowledge, this is the first study to report heritability estimates for VIA traits in lamb. Several authors have reported genetic parameters of carcass composition measured by MLC-CF scores, ultrasound and CT (Conington *et al.* 1998; Puntila *et al.* 2002; Roden *et al.* 2003; Jones *et al.* 2004; Nasholm 2004; Karamichou *et al.* 2006; Van Heelsum *et al.* 2006; Kvame and Vangen 2007).

In a study on crossbred lambs, Jones *et al*. (1999) reported heritability estimates of 0.24 for MLC conformation scores and 0.20 for fat class, respectively. A later study by Karamichou *et al.* (2006) reported similar results, with 0.22 for MLC conformation and 0.25 for fat class. These heritability estimates of carcass composition based on MLC scores are in the same range as those found in this study for most of the VIA traits (LEG:0.20, LOIN:0.26 and BREAST:0.23). However, because it is difficult to asses a subjective measure accurately, we found that MLC scores had lower heritability estimates (0.09 for conformation scores and 0.13 for fat class) than the ones reported by Conington *et al.* (1998). VIA data are collected with a higher degree of accuracy than MLC scores because VIA is less influenced by environmental factors, thus reducing the residual variance, which would increase the estimates of genetic variance. In addition, using VIA system in selection programmes could provide an advantage over MLC scores since decisions to improve carcass quality could be made based on joint cuts with high value rather than on conformation and fatness of the whole carcass.

Heritability estimates for performance traits at constant age were moderate. The heritability estimate for ADG (0.25) found in this study was in the same range as the one reported by several authors (Sinha and Singh 1997; Mousa *et al.* 1999; Bromley *et al.* 2000; Bibe *et al.* 2002; Cammack *et al.* 2005). Using the same model in a study on Sabi sheep, Matika *et al.* (2003), reported a lower heritability estimate of 0.17 for ADG. The heritability estimate for SW (0.28) is in the range of other published studies with estimates ranging from 0.20 to 0.29 (Ap Dewi *et al.* 2002; Karamichou *et al.* 2006; Van Heelsum *et al.* 2006). Wolf and Jones (2007) presented a lower heritability estimate of 0.19 for Texel lambs when the maternal genetic effect was included in the model. In a purebred population of Finnsheep, Puntila *et al*. (2002) reported a higher heritability estimate of 0.44 for live weight before slaughter than the estimate for SW (0.28) found in this study.

The ultrasonic measures, UMD and UFD, on crossbred lambs at constant age were both moderately heritable (0.35) and were similar to those reported in the literature (Lauridsen 1998; Jones *et al.* 2004; Karamichou *et al.* 2006; Wolf and Jones 2007; Ingham *et al.* 2007). Lower estimates of heritability for UMD and UFD, ranging from 0.20 to 0.28, were found by other authors (Conington *et al.* 1998; Roden *et al.* 2003; Van Heelsum *et al.* 2006; Wolf and Jones 2007). Husain *et al.* (2007) for Beulah Specklefaced sheep reported a low heritability estimate for UMD of 0.18 when the maternal genetic effect was included in the model. Higher heritability estimates for UMD and UFD were found by Puntila *et al.* (2002) in a Finnsheep population (0.46) and by Roden *et al.* (2003) for Scottish Blackface sheep (0.44).

The direct heritability estimate for CCW in the present study was of 0.55. A wide range of heritability estimates for cold carcass weight has been published. Lower heritability estimates were found in previous studies for CCW in the range of 0.08-0.15 when the maternal genetic effect was fitted in the model for CCW on crossbred and Swedish breed lambs (Pollott *et al.* 1994; Nasholm 2004). Conington *et al.*

(1998) reported a moderately high value of 0.39 for cold carcass weight of Scottish Blackface lambs. A similar heritability estimate of 0.36 was presented by Ingham *et al.* (2007) for a crossbred lamb population.

3.4.3 Relationships between traits

Genetic and phenotypic correlations were high among VIA traits. This was expected as VIA traits consisted of the different joints LEG, CHUMP, LOIN, BREAST and SHOULDER, which are highly correlated with each other and with the overall carcass or live weight. Therefore, for most of the VIA traits, selection for high primal yield of any of the joints will result in a high correlated response of primal yield of all other joints. The high correlation (above 0.83) between LEG and the other VIA traits is of special interest as it implies a selection based on any of the other primal cuts, CHUMP, LOIN, BREAST and SHOULDER, will result in an improvement of LEG primal yield, which is one of the most valued cuts of the lamb carcass. In addition, a previous study showed that, using the VIA system, the LEG was the most accurately predicted of the primal cuts (Rius-Vilarrasa *et al.* 2009b, Chapter 2).

Estimates of genetic correlations between VIA traits and the carcass traits currently measured in the selection programmes for terminal sires (purebred) it indicate that is relevant to include VIA traits in the breeding programmes to improve carcass value in addition to the ones already used. In particular, the relationship between VIA traits and UFD is of special interest, since one of the breeding goals in the sheep industry is to reduce the level of carcass fatness while increasing the overall carcass meat yield. In the present study, most likely due to the structure of the dataset, (the lambs with VIA records did not have ultrasound measurements although both datasets were closely connected genetically by pedigree information) the results showed that VIA traits were not significantly correlated with UFD. However, VIA traits were favourably correlated to other performance traits (ADG, SW or CCW), meaning that a positive selection response could be achieved by including these traits in a breeding program targeting carcass traits. Further investigations, focusing on the correlations between ultrasonic measures on terminal sires and VIA traits on crossbred lambs are required if the VIA traits are to be included in the selection programmes to improve carcass value. In addition, the value of including VIA traits in the selection programmes will depend not only how useful they are in providing information on carcass composition, but also on the economical incentive placed on these traits, which in turn will influence the producer's breeding decisions.

Estimates of genetic correlations of performance traits were very strong among ADG, SW and CCW and indicated the selection for high ADG will increase finishing lamb weight. These genetic correlations corroborate the findings reported by several authors (Pollott *et al.* 1994; Sinha and Singh 1997; Mousa *et al.* 1999; Miraei-Ashtiani *et al.* 2007). Increasing the weight of lamb carcasses will increase the economic value of each carcass because SW and CCW have been found to be strongly correlated with total price (Conington *et al.* 1998; Karamichou *et al.* 2006). The current carcass quality evaluation system includes, in addition to the conformation and fat scores, the CCW as a payment criterion to the producer. It is therefore crucial that the genetic correlation of CCW with ADG and SW is favourable. In the present study, the selection for high ADG, SW and CCW would not imply an increase in overall carcass fatness as measured using ultrasound. These results agree with the moderate to high negative genetic correlations reported by Conington *et al.* (1998) of scanning weight and cold carcass weight with fat depth of Scottish Blackface sheep.

The relationship between ultrasonic measurements, UMD and UFD at constant age, was negative (-0.22), whereas the phenotypic correlation was slightly positive (0.04). After adjustment for age, Conington *et al.* (1998) also reported a negative genetic correlation (-0.06) between UMD and UFD in Scottish Blackface sheep, albeit of smaller magnitude than the one reported in the current study. Other studies have presented genetic correlations close to zero between UMD and UFD (Ap Dewi *et al.* 2002; Kvame and Vangen 2007), whereas several authors have reported positive genetic correlations between UMD and UFD (Simm and Dingwall 1989; Roden *et al.* 2003; Jones *et al.* 2004; Karamichou *et al.* 2006; Van Heelsum *et al.* 2006; Wolf and Jones 2007; Husain *et al.* 2007)

3.5 Conclusions

Genetic parameters of performance and carcass traits estimated in this study suggest that a favourable genetic response could be made possible by increasing primal meat yield of various carcass cuts without increasing overall carcass fatness. Furthermore, the high repeatability estimates of VIA traits showed that the system is almost free from random errors and would therefore be an accurate way to evaluate meat yield of carcass primal cuts. In addition, the VIA system shows moderate heritabilities of the most valuable carcass joints together with the online capability of tracing the identity of the carcass back to the producer, thus being of a high value for breeding programmes. The strong genetic correlations between primal meat yields among carcass joints suggest that it would be difficult to change the distribution of primal meat yield in each carcass joint independently. However, it also suggests that by using the primal meat yield of one joint, such as LEG, which has the highest correlations with the other joints, it would be possible to improve the meat yield of all the other carcass joints.

To sum up, a selection towards increased carcass value by increasing primal meat yield of the joints, using the VIA system, is possible. The correlations found in this study between VIA traits and performance traits in a crossbred population are favourable and suggest that a combination of these traits in a selection program could be useful. However, the use of VIA traits (on crossbred lambs) in the current selection programmes which include carcass measures on purebred rams needs to be investigated. Further research which would provide a better understanding of the correlation between VIA and ultrasound measurements is needed. The most efficient strategy would be to evaluate VIA traits on crossbred lambs together with ultrasound measures on purebred rams. This would allow the design of the most effective breeding strategy integrating VIA measurements in the current breeding programmes for improved carcass quality.

Chapter 4

Genetic parameters for carcass dimensional measurements from Video Image Analysis and their association with conformation and fat class scores

Abstract

Data on 630 crossbred lamb carcasses was used to estimate genetic parameters for a number of carcass measures, fitting a multivariate animal model using restricted maximum likelihood. Carcass measures included: subjective Meat and Livestock Commission carcass classification for conformation and fat class scores (MLC-CF), primal joint weights predicted using MLC-CF and several carcass linear and area measures obtained by Video Image Analysis (VIA-DM). Heritability estimates for subjective carcass traits (MLC-CF and primal joint weights predicted using MLC-CF) were low (0.05 – 0.17), whereas those for objective carcass traits (linear and area measurements on the carcass from VIA) were moderate to high (0.20 – 0.53). Phenotypic correlations between MLC-CF and VIA-DM were generally low (0.01 – 0.51) and genetic correlations were slightly higher (-0.04 – 0.81), when interpreting their absolute value. The results suggest that the selection for shorter carcasses (VIA lengths) will be associated with improved conformation. Likewise, there was a trend in the genetic correlations between conformation and carcass widths which indicates that conformation could also be improved by the selection for wider carcasses as measured by VIA. The genetic correlations between VIA-DM and fat class scores were only significantly different from zero for the VIA measurement for the leg area (r_g = -0.73). Length traits were highly correlated with each other, with an average genetic correlation of 0.84. Positive genetic correlations (0.47 – 0.85) were found between widths measured on the shoulders and chest with hind leg widths. The areas measured on the carcass were moderately to highly correlated with each other (0.54 – 0.90). In general, genetic correlations which were found to be significant between areas, lengths and widths were moderate to high and positive. Phenotypic and genetic correlations along with heritabilities of the VIA-DM from crossbred lambs, suggest that using this VIA dimensional information in the evaluation of purebred terminal sire breeds is likely to improve conformation on crossbred lambs.

4.1 Introduction

Carcass quality measurements in slaughter lambs are based on the visual appraisal of carcass conformation and fatness, and these criteria are used in payment systems in most European countries (CEC 2002). The use of these subjective carcass assessments in genetic selection programmes has been found to be of negligible benefit, due to their low heritability estimates (Conington *et al.* 2001), and also because of the positive genetic correlation between these two traits (Pollott *et al.* 1994; Jones *et al.* 1999; Conington *et al.* 2001). This limits their use in sheep breeding programmes that aim to improve conformation without an associated increase in fatness. Despite this, due to the relatively large economic weight of these traits, there are cases where they are included in selection indexes along with other important traits, such as maternal characteristics (Conington *et al.* 2001).

Since carcass conformation contributes significantly to the overall value of the slaughter lamb, alternative measures which can describe conformation independently of fatness have recently gained interest in the lamb industry. Measures of muscularity obtained by computer tomography (CT), which by definition is independent of fatness (Navajas *et al.* 2008), have been suggested as alternative methods to improve carcass conformation by genetic selection in purebred sheep (Navajas *et al.* 2007). At present, estimated breeding values (EBVs) for *in vivo* measures of 2D-gigot muscularity obtained by CT (Jones *et al.* 2002; Navajas *et al.* 2007) are available in the UK to assist breeders identify terminal sires with better muscularity of the hind legs.

Linear body traits have also been suggested as objective measures of body conformation in sheep (Waldron *et al.* 1992; Bibe *et al.* 2002). In these earlier studies, linear measurements were recorded manually and were therefore of restricted use in commercial sheep breeding programmes. Conversely, automatic technologies based on video image analysis (VIA) offer the opportunity of recording linear and area traits (dimensional measurements) on the carcass in an objective and automated way, providing a fast and very reliable source of information for genetic improvement programmes. The value of using crossbred information in the genetic evaluation of purebreds has been investigated and the results suggest that this will increase the rate of genetic responses in crossbred progeny (Wei and Van der Verf 1994; Bijma and van Arendonk 1998). In another study, Jones *et al.* (1999) reported that fat class scores taken on crossbred lambs could also be valuable for improving rates of genetic gain in purebred selection programmes.

The introduction of VIA technology to provide information on a range of linear and area measurements on carcasses could eventually encourage the sheep industry towards a new carcass grading and pricing system based upon payments for individual component joints. This change in the carcass evaluation system would be supported by a general shift from subjective carcass quality measures towards a more objective evaluation based on the weight or percentage of meat yields from the different primal joints. In a previous study, Rius-Vilarrasa *et al.* (2009a, Chapter 3) reported genetic parameters for weights of primal carcass cuts predicted using a VIA system. Low to moderate heritabilities were found in that study, suggesting that VIA predictions of primal cut weights could be used in selection programmes to improve weights of individual carcass cuts. However, while the evaluation of carcass quality still relies on the subjective evaluation of conformation and fat class (MLC-CF), genetic parameters of the primal joints weights predicted using the information obtained from these subjective evaluations are also of interest. Prediction models developed to estimate the weight of primal meat yields using MLC-CF have high accuracies (expressed as coefficient of determination, R^2 values) ranging from 0.82 for the breast primal weight and 0.95 for the shoulder primal weight (Rius-Vilarrasa *et al.* 2009b, Chapter 2). Estimates of primal joint weights could be obtained by using the prediction models developed in that previous study along with the MLC-CF scores collected from the present dataset. The predicted primal weights could then be used to estimate genetic parameters for these traits which, to our knowledge, have not yet been investigated. Therefore, the aims of this study were: (1) to estimate genetic parameters for the MLC-CF scores and for primal joint weights predicted from MLC-CF scores, and to compare these results with the results from a previous study (Rius-Vilarrasa *et al.* 2009a, Chapter 3) which used VIA information to predict primal joint weights for leg, chump, loin, breast and shopulder; (2) to investigate the associations between MLC-CF scores and VIA-DM; (3) to estimate genetic parameters for VIA-DM.

4.2 Materials and methods

4.2.1 Animal resource

The 630 crossbred lambs included in this study were produced by mating crossbred Mule ewes (Bluefaced Leicester x Scottish Blackface) with three different terminal sire breeds (Charollais, Suffolk and Texel). A total of 18 sires and 385 dams were used to produce the 630 lambs. Additional pedigree information was available and, after checking for inconsistencies with the software RELAX2 (Strandén and Vuori 2006), the complete pedigree comprised 9261 animals.

The lambs were reared at research farms in Wales (Aberystwyth), England (Rosemaund) and Scotland (Edinburgh) where the lambs' birth weight and sex were recorded. Within 48 hours of lambing, the Mule ewes and their lambs were turned out to pasture. Litters were kept as singles or twins and lambs from larger litters were fostered to another ewe when possible. About 80% of the lambs were reared as twins with the remainder reared as singles. Ewes suckling twin lambs were grazed separately from those with singletons and offered supplementary feeding as required in early lactation. Artificially reared lambs were excluded from this study. More information on the production of Mule ewes, as well as the selection of terminal sire rams is available elsewhere (Jones *et al.* 1999; Simm *et al.* 2001; Van Heelsum *et al.* 2003; Van Heelsum *et al.* 2006).

4.2.2 Carcass measurements on crossbred lambs

The lambs born in 2006 were slaughtered at finished condition (average age 5 months; estimated fat class 3L) at the commercial abattoir of Welsh Country Foods (WCF) in Gaerwen (Wales). Subjective conformation and fat scores were recorded by an expert grader in the abattoir, according to the MLC-CF system. Carcass conformation was assessed using the EUROP five-point scale (where "E" is for excellent and "P" is for poor conformation), and fatness was measured using a five-point scale from 1 (leaner) to 5 (fatter), with scores 3 and 4 sub-divided into "L" (leaner) and "H" (fatter). These subjective grades were then converted to numeric scales, with conformation coded as E = 5, U = 4, R = 3, O = 2, and P = 1 and fatness transformed to a corresponding estimated subcutaneous fat percentage (1 = 4, 2 = 8, 3L = 11, 3H = 13, 4L = 15, 4H = 17 and 5 = 20) (Kempster *et al.* 1986). The lamb's hot carcass weight was recorded just after slaughter and a constant of 0.5 kg deducted as an expected drip loss value to obtain the cold carcass weight (CCW). Prediction equations derived in a previous study by Rius-Vilarrasa *et al.* (2009b, Chapter 2) using MLC-CF scores for the prediction of primal joint weights were used in this study to estimate the weight of LEG, CHUMP, LOIN, BREAST and SHOULDER primal cuts. The prediction models based on MLC-CF and used in the present study were tested and validated in a previous dataset which consisted of 443 observations on dissected primal joint cuts. In that previous study the prediction accuracies reported for the various primal cuts ranged from 0.82 to 0.95 for BREAST and SHOULDER, respectively (Rius-Vilarrasa *et al.* 2009b, Chapter 2). The following prediction model, together with the regression coefficients found in that previous study for each primal cut, was used in the current study to obtain estimated weights of primal joint which were then used to evaluate the genetic parameters of these carcass traits.

$$\hat{Y}_{ijk} = \mu + CONFORMATION_i + FAT_j + b_1(CCW_{ijk}) + e_{ijk} \quad [1]$$

Five prediction models were used to obtain primal joints estimates for each animal l ($\hat{Y}_{ijkl}$), from carcass information on $CONFORMATION_i$ (5 classes: 1, poor conformation to 5, excellent conformation) and on FAT_j (7 classes: 4, very lean to 20, very fat). The CCW_{ijk} was used as a linear covariate where b_1 represents the regression coefficient of Y on CCW and e_{ijk} represents the residual effects.

After the carcasses were subjectively assessed, lambs were redirected from the main slaughter line to a secondary line specifically designed to steer the carcasses to a VIA station for scanning (VSS2000, E+V Technology GmbH, http://www.eplusv.de/), which was installed offline in the abattoir, but run at the typical line speed. Further details on the VIA system have been reported previously (Rius-Vilarrasa *et al.* 2009b, Chapter 2). Carcass linear and area traits (dimensional measurements) were obtained from the VIA system by scanning the back and side views of the carcasses. Some of the VIA system measurements that were available in the current study included carcass lengths (L1 - L4), widths (W1 - W8) and areas (A1 – A4) and are presented in Figure 4.1.

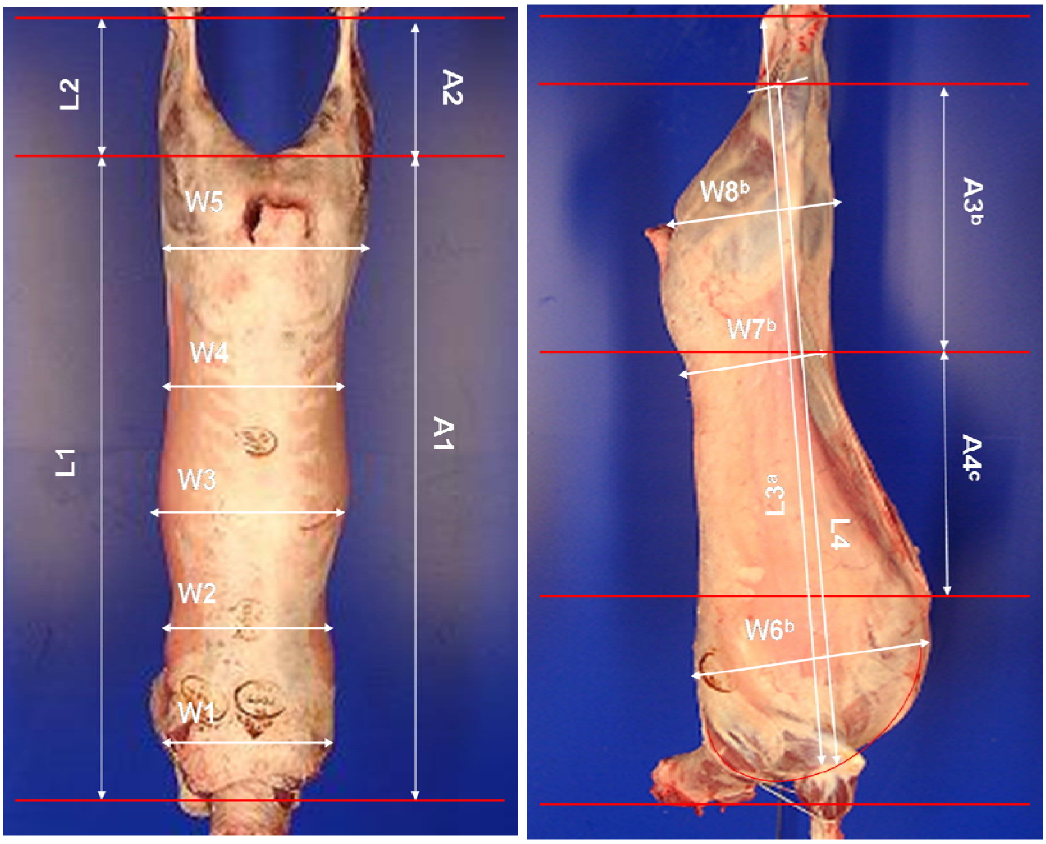

Figure 4.1 Dimensional measurements, lengths, widths and areas of back and side views of the carcasses obtained by VIA.

[a] straight line through the centre of gravity

[b] orthogonal to the centre of gravity

[c] vertical in a 90 degree angle to the dividing line

4.2.3 Statistical analysis

Restricted maximum likelihood (REML) methods were used to estimate (co)variance components based on an animal model using the ASReml program (Gilmour *et al.* 2002). The general animal model, used to estimate heritabilities as well as genotypic and phenotypic correlations for MLC-CF (conformation and fat class), primal joint weights and VIA-DM was as follows:

$$Y_{ijkl} = BH_i + DA_j + BR_k + b_1(AS_{ijkl}) + a_l + e_{ijkl},\qquad [2]$$

where $\boldsymbol{Y_{ijkl}}$ is the record for animal $\boldsymbol{l}$, $\boldsymbol{BH_i}$ is the combined fixed effect of ith year of birth, sex and farm (batch); $\boldsymbol{DAj}$ is the effect of jth dam age; $\boldsymbol{BR_k}$ is the effect of kth sire breed; $\boldsymbol{AS_{ijkl}}$ is the age at slaughter as a covariate where $\boldsymbol{b_1}$ represents the regression coefficient of $\boldsymbol{Y}$ on slaughter age. The random effects $\boldsymbol{a_l}$ and $\boldsymbol{e_{ijkl}}$ represent the direct additive effect of the animal and the residual effects, respectively.

Firstly, univariate analyses were performed to evaluate the significance of different fixed and random effects in the model for the traits listed in Table 4.1 and Table 4.2. The fixed effects included in the analysis were: batch (year of birth [1 class: 2006], sex [2 classes: male and female] and farm [3 classes: Wales, England and Scotland]), sire breed (3 classes: Texel, Charollais or Suffolk) and age of the dam (4 classes: 6 to 8 and >8). All traits were adjusted for age at slaughter, which was fitted in the models as a linear regression. To evaluate the significance of a random effect in the model, a likelihood ratio test was performed that compared reduced and full models, with one degree of freedom, to a critical value from the chi-square distribution. Besides the residual effect, the final models included only the direct additive effect as random effect. The random common environmental effect (litter) was tested but found not to be significant. Following the univariate analysis, multivariate analyses were performed using the most parsimonious model for each trait.

4.3 Results

4.3.1 Heritability estimates

Heritability estimates and their standard errors for MLC-CF traits and for MLC-CF based predictions of the primal joints are presented in Table 4.1.

Table 4.1 Means, phenotypic standard deviations (SD) and heritabilities (h^2) for EUROP scores and primals joint weights

Trait	Abbreviation	Mean	SD	h^2	s.e.
MLC scores					
Conformation (1-5)	CONF	2.92	0.47	0.10	0.07
Fat class (4-20)	FAT	10.4	1.92	0.10	0.07
Predicted primal joints (kg)					
Leg primal joint	LEG	4.29	0.52	0.17	0.08
Chump primal joint	CHUMP	0.71	0.09	0.06	0.06
Loin primal joint	LOIN	2.83	0.37	0.05	0.05
Breast primal joint	BREAST	1.43	0.21	0.06	0.06
Shoulder primal joint	SHOULDER	4.77	0.64	0.09	0.07

Heritability estimates from MLC-CF traits were low for conformation and fatness (both 0.10). Heritability estimates for weights of primal joints predicted using MLC-CF ranged from 0.05 to 0.17, with the lowest value for the LOIN and the highest for the LEG. All heritabilities, except for the primal LEG, were not significantly different from zero.

Table 4.2 Means, phenotypic standard deviations (SD) and heritabilities (h^2) for the VIA dimensional measurements

Trait	Abbreviation	Mean	SD	h^2	s.e.
VIA lengths (cm)					
Length legs to shoulders	L1	77.32	3.67	0.25	0.10
Length hock to legs	L2	21.73	1.47	0.44	0.13
Total length hock to shoulder†	L3	93.40	3.73	0.46	0.11
Half length of tibia to shoulder	L4	79.57	3.23	0.36	0.12
VIA widths (cm)					
Maximum shoulder width	W1	19.05	1.35	0.23	0.10
Minimum breast width	W2	15.92	1.00	0.36	0.11
Maximum breast width	W3	22.08	1.35	0.38	0.12
Minimum waist width	W4	19.26	0.94	0.34	0.11
Maximum legs widths	W5	23.38	0.75	0.39	0.10
Maximum breast width§	W6	25.53	1.86	0.23	0.08
Minimum waist width§	W7	12.87	0.77	0.27	0.10
Maximum legs widths§	W8	15.76	1.15	0.20	0.10
VIA areas (cm^2)					
Back area of the carcass minus legs	A1	153.62	11.67	0.34	0.10
Back area of the legs	A2	19.36	1.79	0.53	0.15
Side area of the hind legs§	A3	48.36	4.11	0.25	0.09
Side area of the saddle¥	A4	65.06	5.95	0.23	0.09

† straight line through the centre of gravity

§ orthogonal to the centre of gravity

¥ vertical in a 90 degree angle to the dividing line

Heritability estimates for VIA-DM were moderate to high (Table 4.2). For VIA-DM, the lowest heritability estimate of 0.20 was for the width W8, located in the leg region, and the highest of 0.53 was for the area A2, which measures the leg joints. Heritability estimates for length traits ranged from 0.25 for L1 and 0.46 for L3. Similar heritabilities were found for carcass width traits with the lowest being 0.20

and the highest 0.39 for width measures near the hind legs, W8 and W5, respectively. VIA-DM measured areas on the carcass showed heritabilities ranging from 0.23 for the saddle area (A4) to 0.53 for an area measuring a section of the hind legs (A2). In summary, for the VIA-DM, the traits with the highest heritability estimates were those related to measurements in the leg region, such as length trait L2 (0.44), width W5 (0.39) and area A2 (0.53).

4.3.2 Estimates of phenotypic and genetic correlations

Phenotypic and genetic correlations between primal joint weights predicted using MLC-CF were all very high (> 0.84), are presented in Table 4.3.

Table 4.3 Estimates of phenotypic (above) and genetic (below) correlations (standard errors) for primal joint weights estimated using MLC-CF on crossbred lambs†

Trait	LEG	CHUMP	LOIN	BREAST	SHOULDER
LEG		0.91	0.84	0.86	0.93
CHUMP	0.98 (0.11)		0.98	0.99	0.98
LOIN	0.92 (0.18)	0.97 (0.04)		0.99	0.96
BREAST	0.84 (0.16)	0.97 (0.03)	0.99 (0.01)		0.97
SHOULDER	0.93 (0.06)	*	0.99 (0.07)	0.98 (0.04)	

† At constant age
* Out of parameter space

The genetic correlation between CHUMP and SHOULDER could not be estimated. Variance structures were set to allow negative parameters to be calculated in the (co)variance matrix leading to non-positive definite matrices. Restricted positive define matrices were also tested, which kept variances in the theoretical parameter space so correlation parameters would not exceed ±1. However, no standard errors could be estimated. These results suggested that CHUMP and SHOULDER might have a very high linear dependency, thus genetic correlations could not be estimated. Estimates of genetic and phenotypic correlations between MLC-CF and VIA-DM are presented in Table 4.4.

Table 4.4 Genetic (r_g, with standard errors, s.e.) and phenotypic† (r_p) correlations between VIA dimensional measurements with conformation and transformed fat class scores§

	CONF		FAT	
	r_g (s.e.)	r_p	r_g (s.e.)	r_p
L1	-0.27 (0.51)	-0.10	-0.04 (0.45)	0.18
L2	**-0.78 (0.24)**	-0.41	-0.55 (0.32)	-0.23
L3	**-0.65 (0.30)**	-0.04	-0.46 (0.38)	0.09
L4	**-0.76 (0.23)**	-0.12	-0.62 (0.33)	0.01
W1	0.12 (0.58)	0.20	0.09 (0.48)	0.23
W2	-0.44 (0.58)	0.26	-0.18 (0.66)	0.40
W3	0.63 (0.38)	0.24	-0.37 (0.43)	0.23
W4	0.81 (0.42)	0.28	0.26 (0.41)	0.27
W5	0.40 (0.47)	0.32	-0.39 (0.41)	0.22
W6	-0.17 (0.58)	0.09	0.24 (0.48)	0.17
W7	0.70 (0.51)	0.51	0.29 (0.43)	0.34
W8	-0.15 (0.59)	0.18	0.33 (0.43)	0.38
A1	0.07 (0.53)	0.27	-0.16 (0.47)	0.34
A2	**-0.80 (0.18)**	-0.28	**-0.73 (0.25)**	-0.16
A3	-0.43 (0.48)	0.20	-0.10 (0.52)	0.33
A4	-0.33 (0.46)	0.09	0.11 (0.43)	0.22

† Standard errors for phenotypic correlations are less than 0.05

§ Significant genetic correlations different from zero in bold

Phenotypic correlations were negative between VIA carcass lengths and CONF, whereas between VIA carcass widths and CONF were all positive ranging from 0.09

to 0.51. The phenotypic correlations between VIA carcass lengths and widths with FAT were in general positive. Looking at the genetic correlations, most of the linear traits were negatively and, in general, strongly correlated with CONF. However, only a few were significantly different from zero, due to high standard errors. No significant associations were found between linear traits and FAT. The reasons for this might be a consequence of the sample size and/or the nature of the traits. Strong negative correlations were found between carcass lengths (L2, L3 and L4) and CONF, which suggests that the selection for longer carcasses will lower the value of the carcass by reducing conformation scores. However, this could possibly be outweighed by an increase in carcass weight and a possible reduction in fatness, as suggested by the genetic correlations in Table 4.4, although large standard errors make the correlations non-significant. The selection for wider carcasses could improve carcass conformation, as shown by the trend on the positive genetic correlations between carcass widths (W3 and W4), as measured on the saddle, and CONF. However these associations were also not significantly different from zero. A significant strong and negative correlation was found between the back area of the legs (A2) with FAT (-0.73) and the same area measure was also negatively correlated with CONF (-0.80). These correlations indicate that the selection for an increased leg area (A2) as measured by VIA could result in a reduction of the overall carcass CONF, which could also be accompanied by a reduction of carcass fatness.

Phenotypic and genetic correlations among VIA-DM are presented, together with their corresponding standard errors, in Table 4.5. Most phenotypic correlations were significant and different from zero, with no standard errors greater than 0.05. However, there were large standard errors for several of the genetic correlations, in particular those correlations of low to moderate absolute magnitude. In general, those genetic correlations that were significantly different from zero were higher in their absolute value than the corresponding phenotypic correlations. In the paragraph below, the estimates of genetic correlations, which were found to be significantly different from zero, within the group of traits, lengths, widths and areas will be presented first. Then, the correlation estimates between the groups of traits will be presented.

Length traits were highly genetically correlated with an average of 0.84. The lowest genetic correlation (0.68) was between L1 and L2 traits and the highest (0.98) between L3 and L4 traits, which indicates a high correlated response for these traits. Positive and moderate to strong genetic correlations (0.47-0.85) were found between widths measured on the shoulders as well as chest areas (W1 and W2) and widths measured on the hind legs (W5, W7 and W8). This implies that selection towards carcasses with wider hind legs could also increase chest and shoulder widths due to a high correlated response between traits. The areas measured on the carcass by VIA were moderately to highly genetically correlated with each other (0.54 – 0.90), which implies that selection to increase any of the carcass areas will increase the rest of the areas as a correlated response.

The lengths were in general lowly to moderately correlated with the widths of the carcass, and most of the estimates with low correlations were not significantly different from zero. The carcass length (L3) measured on the side of the carcass was moderately to highly correlated with W2 (0.51), W5 (0.42), W6 (0.81) and W7 (0.90) widths measured on the back image of the carcass. These correlations are of particular interest for changing the dimension of the carcass by selection. While selection might focus on wider carcasses to increase conformation as reported in the section above, the overall carcass length would not reduce. The genetic correlation between lengths and areas (Table 4.5) shows that longer carcasses would also have larger surface areas. Additionally, increased carcass surface areas would be expected if selection was focused on wider carcasses as shown by the genetic correlations between widths and areas in Table 4.5.

Table 4.5 Phenotypic† (above the diagonal) and genetic correlations§ with standard errors (below diagonal) between VIA dimensional measurements

	L1	L2	L3	L4	W1	W2	W3	W4	W5	W6	W7	W8	A1	A2	A3	A4
L1		0.20	0.68	0.66	0.08	0.20	0.35	0.30	0.53	0.47	0.37	0.24	0.82	0.29	0.42	0.58
L2	**0.68 (0.21)**		0.52	0.58	0.03	-0.05	-0.05	-0.08	-0.05	0.28	0.05	-0.05	0.27	0.87	0.22	0.49
L3	**0.95 (0.05)**	**0.69 (0.14)**		0.97	0.30	0.31	0.41	0.30	0.58	0.66	0.62	0.25	0.78	0.68	0.86	0.90
L4	**0.90 (0.07)**	**0.83 (0.09)**	**0.98 (0.01)**		0.25	0.23	0.35	0.21	0.35	0.58	0.25	0.20	0.68	0.65	0.70	0.81
W1	0.40 (0.30)	0.48 (0.30)	0.27 (0.28)	0.13 (0.27)		0.76	0.34	0.42	0.48	0.16	0.34	0.35	0.49	0.19	0.42	0.33
W2	-0.12 (0.40)	0.22 (0.35)	**0.51 (0.17)**	-0.57 (0.29)	**0.65 (0.19)**		0.52	0.52	0.61	0.20	0.47	0.43	0.75	0.09	0.50	0.33
W3	0.21 (0.31)	0.11(0.30)	0.28 (0.23)	0.16 (0.22)	0.00 (0.23)	-0.22 (0.32)		0.72	0.41	0.26	0.14	0.17	0.76	0.03	0.25	0.37
W4	0.47 (0.34)	-0.05 (0.28)	0.31 (0.25)	0.23 (0.23)	0.19 (0.27)	-0.13 (0.34)	**0.80 (0.09)**		0.52	0.20	0.28	0.25	0.67	-0.01	0.30	0.31
W5	**0.55 (0.25)**	**0.52 (0.24)**	**0.42 (0.16)**	0.16 (0.21)	**0.78 (0.12)**	**0.47 (0.17)**	-0.04 (0.22)	0.30 (0.23)		0.20	0.59	0.43	0.80	0.23	0.68	0.52
W6	**0.72 (0.17)**	0.14 (0.25)	**0.81 (0.11)**	**0.71 (0.14)**	0.02 (0.36)	-0.51 (0.45)	0.11 (0.35)	0.25 (0.27)	-0.50 (0.24)		0.34	0.16	0.57	0.33	0.47	0.75
W7	**0.81 (0.23)**	-0.21 (0.32)	**0.90 (0.08)**	0.56 (0.31)	0.65 (0.27)	**0.82 (0.11)**	-0.04 (0.35)	0.55 (0.28)	**0.50 (0.18)**	**0.85 (0.24)**		0.48	0.65	0.14	0.81	0.70
W8	-0.10 (0.38)	-0.07 (0.29)	-0.06 (0.31)	-0.06 (0.35)	**0.74 (0.18)**	**0.76 (0.21)**	-0.51 (0.27)	0.04 (0.30)	0.33 (0.28)	0.04 (0.38)	0.20 (0.24)		0.42	0.05	0.72	0.62
A1	**0.82 (0.12)**	0.52 (0.25)	**0.91 (0.05)**	0.59 (0.21)	0.41 (0.31)	**0.82 (0.08)**	**0.59 (0.18)**	**0.75 (0.14)**	**0.61 (0.13)**	**0.68 (0.23)**	**0.98 (0.05)**	-0.24 (0.45)		0.30	0.80	0.62
A2	**0.59 (0.22)**	**0.95 (0.03)**	**0.89 (0.07)**	**0.91 (0.07)**	0.47 (0.29)	-0.14 (0.37)	-0.33 (0.23)	-0.42 (0.24)	0.11 (0.29)	-0.06 (0.33)	-0.19 (0.28)	-0.23 (0.33)	**0.54 (0.22)**		0.30	0.48
A3	**0.84 (0.15)**	0.49 (0.25)	**0.95 (0.04)**	**0.80 (0.15)**	0.31 (0.32)	**0.61 (0.17)**	-0.42 (0.25)	-0.08 (0.30)	**0.67 (0.21)**	0.34 (0.35)	**0.96 (0.04)**	0.50 (0.26)	**0.90 (0.06)**	0.49 (0.28)		0.78
A4	**0.96 (0.07)**	0.51 (0.21)	**0.90 (0.06)**	**0.82 (0.10)**	0.23 (0.33)	-0.64 (0.43)	0.22 (0.26)	0.47 (0.24)	**0.39 (0.19)**	**0.93 (0.11)**	**0.83 (0.15)**	**0.79 (0.13)**	**0.72 (0.16)**	0.41 (0.25)	**0.71 (0.17)**	

† Standard errors for phenotypic correlations are less than 0.05.

§ Significant genetic correlations different from zero in bold

4.4 Discussion

In the present study, heritabilities for MLC-CF scores and VIA-DM were estimated, along with their phenotypic and genetic correlations. Low heritabilities were found for MLC-CF traits conformation (0.10) and fat class (0.10). This is likely to be a reflection of the subjective nature of this assessment, which probably inflates the environmental variance. In addition, categorical traits analysed under the hypothesis of a normal distribution might also have influenced the accuracies of the genetic parameter estimates for these traits. Despite CONF and FAT scores, observations were classified as normally distributed (Skewness: -0.54 and 1.23 and Kurtosis: 3.17 and 4.0, for CONF and FAT, respectively). The analysis of those traits using Bayesian statistics, particularly for genetic evaluations of traits with discrete and non-normal distributions (Van Tassell *et al.* 1998; Blasco 2001) might have provided slightly higher heritability estimates. No references using Bayesian statistics on these traits have been found in the literature, however several authors have reported genetic parameters for MLC-CF using maximum likelihood methods with a fairly wide range of heritability estimates (Conington *et al.* 1998; Jones *et al.* 1999; Puntila *et al.* 2002; Karamichou *et al.* 2006; Van Heelsum *et al.* 2006). Conington et al (1998), in a study on Scottish Blackface hill lambs, reported heritability estimates for fat class (0.09) and EUROP conformation class (0.13) similar to the present study. Other studies reported higher heritability estimates, on average of 0.23 for conformation and 0.22 for fat class (Jones *et al.* 1999; Karamichou *et al.* 2006). Although there are limitations to improving carcass conformation through genetic selection, due to its positive correlation with fatness in a wide range of breeds (Lewis *et al.* 1996; Conington *et al.* 1998; Jones *et al.* 1999; Moreno *et al.* 2001; Bibe *et al.* 2002; Karamichou *et al.* 2006), sheep breeders are still interested in improvement of this trait, mainly for its economic impact.

An alternative way to improve carcass conformation could be by indirect selection on measures associated with carcass shape, such as body and carcass linear traits. Moderate to high genetic and phenotypic correlations between carcass shape (conformation) and linear carcass measurements were found in the present study, which were comparable with some found in the literature (Waldron *et al.* 1992; Bibe *et al.* 2002). However, they were in disagreement with results reported by Pollott *et al.* (1994) and Janssens and Vandepitte (2004), where no associations were found between shape, as assessed by conformation scores, and body measurements. Improvement of carcass conformation by altering the carcass shape could be due to changes in weight of the muscle relative to a skeletal dimension (length of the bones), defined as muscularity by Purchas *et al.* (1991). Recent work reported by Navajas *et al.* (2007) confirmed this association, where strong phenotypic correlations were found between subjective conformation score and muscularity as measured *in vivo* by CT in lambs from two divergent breeds that are of economic importance in the UK (Texel and Scottish Blackface). Another study by Wolf and Jones (2007) also reported that an improvement of leg shape by a reduction in length of the limb would improve leg muscularity. These changes in leg shape were also expected to give improvements in overall carcass shape (conformation). Collectively, these results agree with those of Laville *et al*. (2004), who found that conformation was strongly influenced by leg muscularity.

While selection for shorter or wider carcasses as measured in the present study could improve carcass conformation, and as a result also increase muscularity of primal cuts, this should be investigated carefully. There is a possibility that selection for shorter carcass lengths could lead to smaller carcass size with less cold carcass weight, hence resulting in an economic loss for the producer as payments are based mainly on carcass weight. In addition, genetic correlations between VIA-DM and FAT also showed a moderate correlation in the same direction as for CONF, indicating that selection for linear traits to improve carcass CONF could also be associated with an increase in carcass fatness. While these genetic correlations were associated with large standard errors, the results have been based on a trend in the data, and therefore further analysis is required to confirm the associations between these carcass traits. However, literature references have been found that support the results found in the present study. Comparable results were reported by Moreno *et al.* (2001), where selection for shorter carcass length improved carcass conformation accompanied with an increase in fatness (internal fat score), as estimated by kidney fat area. The results of this study indicate that VIA information could help in the improvement of carcass CONF by genetic selection, but the associations between VIA-DM with FAT need to be further investigated, because dissected carcass information was not available on these lambs. In addition, future research into the associations between VIA-DM and muscularity measurements are highly relevant, since VIA information from crossbred lambs could be used in current commercial breeding programmes to increase genetic progress to improve muscularity in purebred animals.

There are few published estimates of genetic parameters of linear and area type traits on sheep carcasses and the ones found in the literature are very difficult to compare due to differences in the measures taken. In the present study, heritability estimates for linear and area carcass traits measured on VIA images were moderate to high (0.20 – 0.53) and were within the range of the heritability estimates for linear type traits in sheep measured on the carcass and on live animals reported by several authors for sheep (Moreno *et al.* 2001; Janssens *et al.* 2004; Gizaw *et al.* 2008) and also for beef and dairy cattle (Brotherstone 1994; Mukai *et al.* 1995). In general, linear traits have been used as indirect measures of relevant economic traits, such as conformation, performance and production traits (Brotherstone 1994; Janssens and Vandepitte 2004; Gizaw *et al.* 2008). However, the responses to selection on VIA-DM, as a direct measure of carcass shape with the potential to alter carcass dimensions, were also investigated. The results found in the present study suggested that it would be difficult to select for larger hind legs (longer and wider) without a correlated increase in the length of the whole carcass. The selection of carcasses with larger hind legs would also be accompanied by increasing carcass chest and shoulder width. The latter might be undesirable if associations are found with increased incidence of lambing difficulties. In general, it would be difficult to alter the carcass shape by genetic selection based on the group of significant genetic correlations between VIA-DM found in the present study. Further analysis in order to elucidate the associations between VIA-DM and dissected primal weights could also help to provide information on selection for increased dimensions of the most valuable primal cuts, as long as these did not result in increased lambing difficulty, but data on the weights of these cuts were not available in these crossbred lambs.

The abattoirs and processing sectors would like to move towards a pricing system based on weight of lean meat in primal joints. It is possible that VIA systems could be introduced in UK lamb abattoirs in the next few years which can predict weights of primal joints with high accuracies (ranging from 0.86 to 0.97 for dissected primals loin and leg cuts; Rius-Vilarrasa *et al.* 2009b, Chapter 2). However, it is unlikely that VIA systems will be simultaneously installed across all lamb abattoirs. Therefore, it was of considerable interest to investigate the genetic response that could be achieved by selection for improved weights of primal meat yields predicted using the current EUROP carcass grading. Low heritability estimates (0.05 – 0.17) were found for predicted weights of primal meat yields using the current EUROP conformation and fat scores. Using the same dataset and VIA information to predict the weight of the primal cuts, higher heritability estimates (0.07 – 0.26) were found in a previous study (Rius-Vilarrasa et al. 2009a, Chapter 3). These differences in heritability estimates might be due to greater a environmental variance associated with subjective measures of carcass quality compared to the objective measures obtained by VIA. Additionally, while VIA systems can allow for further improvements in accuracy of prediction of primal weights by re-adjusting the prediction equations with the continuous scanning of carcasses online in abattoirs, MLC-CF have smaller margins for improvement. Therefore, the use of primal weights predicted using VIA to improve carcass composition in selection programmes would provide an initial faster response to selection, than the use of MLC-CF scores.

4.5 Conclusions

Carcass quality measures are currently based not only on carcass weight, but also on CONF and FAT as visually assessed by an expert grader. However in the near future, measures of saleable meat yield might also be used as a measure of carcass quality in UK abattoirs. Estimates of heritability found in this study for CONF and FAT class and for primal joint weights evaluated using MLC-CF, indicate that the additive genetic variability of these traits is low and would lead to a low response to selection for improved carcass quality. On the contrary, heritability estimates found for the VIA-DM suggest that the use of these traits in genetic improvement programmes could lead to a faster response to selection for improved carcass conformation. Further research is required on the associations between muscularity, which represents a measure of shape that is independent of fatness (De Boer *et al.* 1974; Purchas *et al.* 1991), and VIA-DM, since this could provide the means to select for increased meat yield weight without an increase in fatness (Waldron *et al.* 1992; Jones *et al.* 2004). Automatic technologies such as VIA can offer a significant opportunity to record very accurate information on carcass characteristics from crossbred lambs with the possibility to feed this information back from the abattoir to the producers and breeders to enable far more information on important carcass traits to be used in genetic evaluations, thereby increasing the accuracy of EBVs and rates of response to selection.

Chapter 5

Effects of a quantitative trait locus for increased muscularity on carcass traits measured by EUROP scores and Video Image Analysis in crossbred lambs

Abstract

A QTL, for increased loin muscularity (TM-QTL), has previously been identified in purebred Texel sheep. Crossbred lambs born out of Mule ewes mated to heterozygous Texel sires for the TM-QTL were evaluated for a range of carcass traits. Lambs were genotyped and classified as carriers (n = 62) of a single copy of the TM–QTL and non-carriers (n = 49). In this study, the effects of the TM-QTL on carcass attributes were investigated using subjective classification scores for conformation and fatness, and measurements from a Video Image Analysis (VIA) system. In addition, refined prediction equations to estimate weights of primal joints (leg, chump, loin, breast and shoulder) were obtained by calibrating the VIA system against Computer Tomography (CT) measurements in the loin region. The new refined prediction models increased the accuracy of prediction of all primal cuts by an average of 16% compared to previously derived standard VIA prediction equations. The coefficient of determination (R^2) of the VIA system to predict *in vivo* CT measurements ranged from 0.39 to 0.72 for measurements of *m. longissimus lumborum* (MLL) area, width and depth, lumbar spine length, loin muscle volume and loin muscularity index. Using VIA estimates of CT measured loin muscle traits, a significant increase in depth (+2.7%) of the MLL was found to be associated with the TM-QTL. Conformation and fatness scores and the shape of the carcass measured as individual lengths, widths and areas by VIA were not significantly influenced by the TM-QTL. Primal meat yields estimated using both standard and refined VIA prediction equations were not significantly affected by the TM-QTL. However, the carcass 'compactness', was found to be significantly increased in carrier lambs. The weight of the dissected MLL estimated using VIA information was greater (+2.6%) for carriers compared to non-carriers. To conclude, neither the current industry carcass evaluation system for conformation and fatness nor the standard VIA system is able to identify the effect of the TM-QTL in the loin region at the moment. However, the calibration of the VIA system against CT measurements resulted in improved VIA prediction equations for primal meat yields and also showed moderate potential to estimate loin muscle traits measured by CT and to detect, partially, the effect of the TM-QTL on these traits.

5.1 Introduction

In the UK, the identification of a QTL on OAR 18 by Walling *et al.* (2004) in a Texel sheep population, that increases eye muscle depth by 4 to 8%, has provided an opportunity to increase the efficiency of selection programmes for increased loin muscling. This QTL was later confirmed by another study (Matika *et al.* 2006) and will be referred to here as TM-QTL (short for Texel muscling-QTL). In a recent study using the same population of crossbred as in this study, Macfarlane *et al.* (2008) reported an increase of +6.7% in the *m. longissimus lumborum* depth, with +3.0% in the width and +5.1% in the area as measured by *in vivo* computer tomography (CT) in carriers of a single copy of the TM-QTL. The dissected weight of the *m. longissimus lumborum* was found to be +7.1% greater in the TM-QTL carriers than in the non-carriers.

Some previous studies have found that increased muscularity due to certain mutations can be associated with detrimental effects on meat quality (MQ) (Shackelford *et al.* 1994; Koohmaraie *et al.* 1995; Field *et al.* 1996). While MQ characteristics are very important for the lamb industry, they are very difficult and costly to measure. Currently, commercial lamb carcasses in the UK are evaluated subjectively by an expert grader using the Meat and Livestock Commission (MLC) carcass classification scheme for conformation and fat class (MLC-CF) (Anderson 2003). To improve the accuracy, precision and consistency of the commercial evaluation of lamb carcasses, research is being undertaken to investigate the use of video image analysis (VIA) for the assessment of carcass value. Previous studies have shown that VIA can objectively predict lamb carcass composition (Horgan *et al.* 1995; Stanford *et al.* 1998; Brady *et al.* 2003), with higher accuracy and precision than the subjective MLC-CF classification scheme (Rius-Vilarrasa *et al.* 2009b, Chapter 2). Besides, the use of VIA systems in combination with other carcass grading systems has also been investigated, and the results reported higher safety of the estimations (Branscheid *et al.* 2004) when the VIA system was included in the evaluation. In a recent study, VIA scanning of live lambs has been shown to help in the prediction of MQ by estimating intra-muscular fat (IMF) (Lambe *et al.* 2008b). In addition, Hopkins (1996) showed that VIA could also help to estimate muscularity (muscle shape) as suggested by Purchas *et al.* (1991), based on a function of the weight of the muscle and the length of the bone it surrounds. Consequently, the use of VIA in abattoirs could provide the basis for a payment system based on meat yield as well as offer the possibility to help in the estimation of MQ traits in a non-destructive and cost-efficient way. Therefore, producers willing to use the TM-QTL as a meat yield enhancing QTL could be economically rewarded, whilst any associated effects on MQ could also be monitored.

Therefore, the aims of this study are to evaluate the effect of the TM-QTL on carcass characteristics of crossbred lambs, as an example of a muscle growth enhancing QTL that is likely to be used in the sheep industry. The study will evaluate the effect of the TM-QTL on carcass traits (i.e. conformation, primal joint weights, dimensional measurements and carcass and leg compactness) estimated using both EUROP scores and a VIA system. In addition, effects of calibrating VIA prediction equations using CT measurements will be evaluated. Finally, the ability of the VIA system to predict MQ traits will also be investigated.

5.2 Materials and methods

5.2.1 Experimental animals

A total of 166 crossbred lambs, born in 2006 out of two-year old Mule ewes (Bluefaced Leicester x Scottish Blackface) mated to purebred Texel rams, known to be heterozygous for TM-QTL, were included in this study. All lambs were grazed on pasture at the Scottish Agricultural College (SAC) sheep unit near Edinburgh. Live weight was recorded every five weeks until lambs reached around 20 weeks of age. The four Texel sires used in the experiment were previously identified as heterozygous for the TM-QTL from a population in which the QTL was known to be segregating (Walling *et al.* 2004; Matika *et al.* 2006). All Mule dams were non-carriers of the TM-QTL. Macfarlane *et al.* (2008) described in detail the classification procedure to determine whether lambs were heterozygous for the TM-QTL (carriers) or wildtype (non-carriers). Four microsatellite markers on chromosome 18 were used for genotyping the TM-QTL at Catapult Genetics, New Zealand. Out of the 166 genotyped lambs, 49 lambs were classified as non-carriers, 62 as carriers and 55 had an unknown TM-QTL status. Only three of the four sires used were found to be segregating for the QTL following the genotypic analysis of their progeny; therefore the lambs of uncertain TM-QTL status were either the progeny of the non-segregating sire or the progeny of the other three sires in which it was not possible to assign unambiguously a genotype to them. These lambs were therefore excluded from any analyses involving direct comparisons between heterozygous carrier and non-carrier (wildtype) animals.

5.2.2 Computer tomography

Computer tomography (CT) measurements in the loin area were also available. Measurements of the loin muscle (*m. longissimus lumborum*) obtained by CT scanning and by dissection have shown significant effects of the TM-QTL on several traits, as reported by Macfarlane *et al.* (2008). While the "standard" VIA prediction equations developed by E+V Technology GmbH (http://www.eplusv.de/) did not yield any significant differences between carriers and non-carriers, an attempt was undertaken to refine the VIA prediction equations using data from the CT traits and dissected weight of the *m. longissimus lumborum* (MLL-wt).

Computer tomography scanning *in vivo* was used to obtain both two- and three-dimensional measurements, as described by Macfarlane *et al.* (2008), for all 166 lambs at an average age of 144 days. Two-dimensional (2D) CT measurements were taken in the loin region from a cross-sectional image taken at the 5th lumbar vertebra described in detail by Jones *et al.* (2002) and included the *m. longissimus lumborum* (Figure 5.1) area (MLL-A), width (MLL-W) and depth (MLL-D). Three-dimensional (3D) CT measurements were also taken in the loin area, using contiguous images taken at 8 mm intervals along the body, which are available using spiral CT scanning and can be reconstructed to form a 3D image (Navajas *et al.* 2007). These 3D measurements included lumbar spine length (lumbar length), loin muscle volume (LRMV) and the calculated loin muscularity index (LRMI).

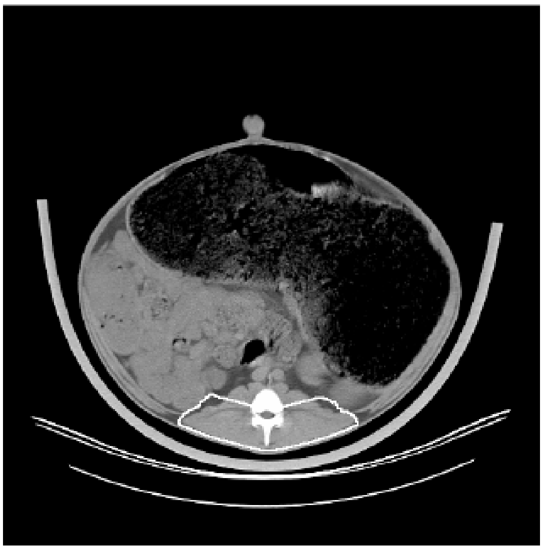

Figure 5.1 Image from a lamb, with the segmentation boundary of *m. longissimus lumborum* super-imposed (white lines) (Navajas 2008)

The CT measurements in the loin region described above were provided to E+V Technology to support investigations to further refine their prediction models for the estimation of primal meat yields from different carcass cuts, in particular in the loin area. These refined prediction equations for primal meat yield were then used in an attempt to enable VIA to distinguish between TM-QTL carriers and non-carriers for the primal weights. From these analyses, E+V Technology also obtained predicted values for the CT measurements for MLL-A, MLL-W, MLL-D, lumbar length, LRMV and LRMI using VIA information. In total, eight predictors (a combination of lengths, areas, widths measured on the carcass by image analysis) were used, together with live weight, to obtain VIA-based estimates of the CT traits. These estimates are also of scientific interest as they demonstrate the predictability of certain CT traits from VIA measurements. Therefore, it was possible to evaluate the effect of the TM-QTL on the CT loin measures based on VIA information and to compare these results with those reported by Macfarlane *et al.* (2008) on the effect of the TM-QTL in the loin region measured directly by CT.

5.2.3 Slaughter, carcass classification, VIA and other carcass traits

At approximately 20 weeks of age (141 to 159 days), lambs were slaughtered under commercial conditions, including a final high-voltage electrical stimulation of the carcass, at Welsh Country Foods (lamb abattoir in Gaerwen). The lambs were assessed according to the MLC-CF carcass classification scheme by an expert grader in the abattoir. Carcass conformation is assessed using the EUROP five-point scale (where “E” is for excellent and “P” is for poor conformation), and fatness, using a five-point scale from 1 (leaner) to 5 (fatter), with scores 3 and 4 sub-divided into “L” (leaner) and “H” (fatter). These subjective grades were then converted to numeric scales, with conformation coded as E = 5, U = 4, R = 3, O = 2, and P = 1 and fatness transformed to a corresponding estimated subcutaneous fat percentage (1 = 4, 2 = 8, 3L = 11, 3H = 13, 4L = 15, 4H = 17 and 5 = 20) (Kempster *et al.* 1986). For VIA scanning, lambs were redirected from the main slaughter line to the VIA station (VSS2000, E+V Technology). The carcass assessment unit of VSS2000 consisted of two cameras, standardised lighting, and the VSS2000 image processing and analysing software. The VIA station also included a metal structure and chain to move the carcasses through at the same speed as the actual slaughter line (800 carcasses/h). The 166 lamb carcasses were presented to the VIA system for image capture in a standardised position with the legs spread apart (on a gambrel hook) and shoulders un-banded. More information on the VIA scanning system has been given earlier (Rius-Vilarrasa *et al.* 2009b, Chapter 2).

VIA system measurements included dimensional characteristics of the carcass and colour variation at selected positions. The relative proportions of fat can be calculated from the pixel colour values extracted from the image. The percentage of different colour pixels allowed, E+V Technology to calculate the level of carcass fatness. However, to estimate weights of primal cuts, E+V Technology used a series of carcass dimensional measurements which included lengths, widths and calculated areas (some are presented in Figure 5.2). These carcass dimensional measurements were used in the current study to investigate the effect of the TM-QTL on carcass attributes.

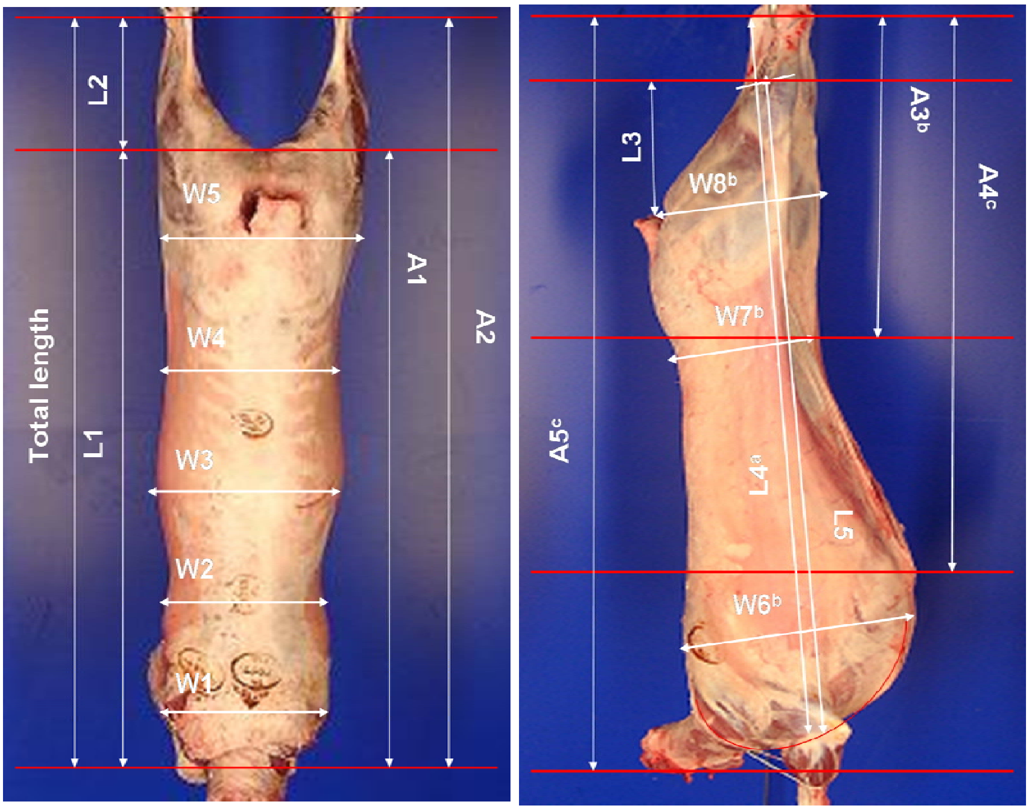

Figure 5.2 Carcass dimensional measurements including lengths, widths and areas of back and side views of the carcasses obtained by VIA.

[a]straight line through the centre of gravity

[b]orthogonal to the centre of gravity

[c]vertical in a 90 degree angle to the dividing line

The VIA meat yield estimates were obtained from the leg (LEG), chump (CHUMP), loin (LOIN), breast (BREAST) and shoulder (SHOULDER) primal cuts, which will subsequently be referred to as VIA primal cuts. The software which captured the image and automatically divided the carcass into different anatomical regions to predict weights of carcass primal cuts (LEG, CHUMP, LOIN, BREAST and SHOULDER) was calibrated and validated under British abattoir conditions on a previous study (Rius-Vilarrasa *et al.* 2009b, Chapter 2). In the present study, carcass dimensional measurements and estimates of meat yield in these primal cuts were used to investigate for any significant differences due to the presence of the TM-

QTL. Furthermore, the effect of the TM-QTL was tested on additional carcass measurements describing other aspects of carcass quality. These carcass measurements were calculated using combinations of VIA dimensional measurements and are referred to in this study as leg compactness, carcass compactness, muscle to bone ratio and fat to bone ratio (Table 5.1).

Table 5.1 Description, means and standard deviations (SD) of computer tomography (CT), Meat and Livestock Commission (MLC) scores, video image analysis (VIA), dissection and meat quality traits

Trait (unit)	Description	Mean	SD
VIA estimates of 2D CT			
MLL-A (cm^2)	Area of the *m. longissimus lumborum*	22.76	3.88
MLL-W (mm)	Width of the *m. longissimus lumborum*	72.63	3.54
MLL-D (mm)	Depth of the *m. longissimus lumborum*	30.44	2.26
VIA estimates of 3D CT			
Lumbar length (cm)	Lumbar spine length	19.84	0.77
LRMV (cm^3)	Loin region muscle volume	672.14	82.07
LRMI	Loin region muscularity index	2.95	0.18
MLC scores			
Conformation	From 1 (poor conformation) to 5 (excellent)	3.02	0.53
Fatness	Subcutaneous fat (1 to 20)	10.81	2.49
VIA primals (kg)			
LEG	Leg primal meat yield	4.72	0.57
CHUMP	Chump primal meat yield	1.55	0.24
LOIN	Loin primal meat yield	2.73	0.36
BREAST	Breast primal meat yield	1.69	0.49
SHOULDER	Shoulder primal meat yield	6.27	0.75
SMY	Saleable meat yield	16.9	2.23
Carcass measurements (ratios)			
Leg compactness	$[W5+W8]^{1/2} / L3$	0.13	0.02
Carcass compactness	W5 / TL	0.24	0.01
Muscle:bone ratio	Muscle weight / bone weight (whole carcass)	2.18	0.17
fat:bone ratio	Fat weight / bone weight (whole carcass)	0.43	0.14
Dissection (g)			
MLL-wt	Average weight of the left and right *m. longissimus lumborum*	508.07	84.16
Meat quality			
ToughA-Loin (kgF)	Loin muscle shear force, Bristol	3.28	1.48
ToughB-Loin (kgF)	Loin muscle shear force, SAC	5.46	1.36
ToughA-Leg (kgF)	Leg muscle shear force, Bristol	3.49	0.79
ToughB-Leg (kgF)	leg muscle shear force, SAC	5.73	0.58
IMF-Loin (%)	Loin muscle intra-muscular fat	2.19	0.8
IMF-Leg (%)	Leg muscle intra-muscular fat	2.32	0.66
CCW	Cold carcass weight (kg)	18.32	2.62

5.2.4 Carcass dissection

After VIA scanning, the 166 lamb carcasses were transported to SAC in Edinburgh, in a refrigerated lorry, for further processing. The right side of the carcass was dissected into primal cuts (leg, chump, loin, breast and shoulder) to match supermarket specifications, with external (subcutaneous) fat trimmed to a maximum of 6 mm. To our knowledge, no literature references have been found regarding carcass side differences and therefore side effects were not considered in the present study for practical reasons. The dissected weights of primal cuts were used in this study to investigate the accuracy and precision of the VIA system in the estimation of primal cuts using (i) the standard and (ii) refined VIA prediction equations.

The left and right *m. longissimus lumborum* (MLL) muscle was removed and weighed separately during the butchery process. Since the dissected weight of the MLL was +7.1% heavier in TM-QTL carriers compared to non-carriers (Macfarlane *et al.* 2008), the MLL-wt was considered to provide information on the differences between carriers and non-carriers. Therefore, the MLL-wt data was provided to E+V Technology, who used VIA information to predict this trait.

Total saleable meat yield in the carcass (SMY) was calculated by summing the weights of boneless chump, chump trimmings (very lean), hind leg-shank-off, hind leg fillet, chops, breast, shoulder knuckleside and bladeside cuts of the right carcass side. More details of the dissection process have been given in another study (Macfarlane *et al.* 2008).

5.2.5 Meat quality

Meat quality (MQ) analyses on leg (*m. vastus lateralis*) and loin (*m. longissimus lumborum*) muscles from all 166 lambs were available as part of the wider project to evaluate the effects of the TM-QTL on MQ characteristics. At between 7 and 12 days post-slaughter, the two muscles, from the leg and loin, from both sides of each lamb carcass were removed, vacuum-packed and then frozen. The two right-hand-side muscles were transported to the University of Bristol for meat quality analyses and the two left-hand-side muscles were analysed at SAC in Edinburgh. Measures of toughness (force (KgF) required to shear the sample) were recorded in both muscles in Bristol and Edinburgh using a similar method, but a slightly different compression equipment. Samples were cooked (in vacuum-pack bags) in water to an internal temperature of 78ºC (in Bristol) and 75ºC (at SAC) and then cooled and held at around 4ºC. Ten sub-samples of 10 x 10 x 20 mm were cut from each muscle in the direction of muscle fibres. In Bristol, muscle samples were sheared, using a TA-XT2 texture analyser (Stable Micro System, Surrey, UK) fitted with Volodkevich-type jaws providing ‘Tough A’ measures. In Edinburgh, cooked samples were analysed using a MIRINZ tenderometer to provide 'Tough B' measures. Measures of IMF were available from Bristol for the two muscles after using petroleum ether (B.P. 40-60 degrees C) as the solvent in a modified Soxhlet extraction. Duplicate measures of IMF were made per animal for the loin to obtain an average. However, the leg muscle was small in many of the lambs, permitting only one IMF analysis per animal. Dimensional measurements from the VIA system were used in the prediction models to estimate MQ traits and accuracy, and precision of these predictions were calculated.

5.2.6 Statistical analysis

From a total of 166 lamb carcasses, only lambs classified as carriers (n = 62) or non-carriers (n = 49) of the TM-QTL were used in the analyses. The accuracy (R^2) and precision (RMSE) with which E+V Technology predicted the primal cuts and CT traits were investigated using general linear model procedure in SAS (SAS Institute Inc., Cary, NC, USA). Two PROC MIXED procedure models were defined as: model [1] only for the primal cuts (LEG, CHUMP, LOIN, BREAST and SHOULDER) and CT traits (MLL-A, MLL-W, MLL-D, LL, LRMV and LRMI); model [2] for all the traits in Table 5.1 and Table 5.2.

$$Y_{ijlm} = \mu + sex_i + TMQTL_j + b_1 \times VIAestimate_l + e_{ijlm} \quad , \qquad [1]$$

$$Y_{ijklm} = \mu + sex_i + TMQTL_j + sire_k + b_1 \times CCW_l + e_{ijklm} \quad , \qquad [2]$$

where, $\boldsymbol{Y_{ijklm}}$ and $\boldsymbol{Y_{ijlm}}$ are the vectors of observations, for the traits presented in Table 5.1 and Table 5.2 of the *m*th individual with fixed effects of *i*th ***sex***, *i* varying from 1 to 2 (male or female), of *j*th ***TM-QTL*** status, *j* varying from 1 to 2 (carrier or non-carrier), random effect of *k*th ***sire***, *k* varying from 1 to 3, of *l*th ***VIAestimate*** (of primal cuts and CT traits) and cold carcass weight (***CCW***), and linear regression coefficient b_1 of VIA-estimates and CCW for *m*th individual with general mean μ and random residual effects of $\boldsymbol{e_{ijklm}}$ and $\boldsymbol{e_{ijlm}}$. The sire effect and the age of the lambs at slaughter were also tested, but were found not to be significant for most of the traits in model [2] and were therefore not included in the final model used for the analysis. The rearing rank of the lamb (single or twin) was significant ($P < 0.05$) for only one trait (W3) and was therefore only included in the analysis of this trait. No significant interactions between fixed effects were found on any of the traits.

A forward stepwise regression analysis was used, with the SAS REG procedure, to identify which of the main VIA dimensional measurements explained most of the variation in MQ traits. VIA dimensional measurements found to be significant ($P < 0.05$) were then fitted in a regression model, using the REG procedure as implemented in SAS. This procedure provides, in addition to the coefficient of regression, the adjusted coefficient of determination (Adj-R^2) accounting for the number of factors included in the model. The effect of sex, as a fixed effect, and CCW, as covariate, were also included in the prediction models for MQ traits. The accuracies of the prediction models used to estimate MQ traits were investigated using the corresponding Adj-R^2 and the root mean squared error (RMSE) divided by standard deviation (SD). The Adj-R^2 was used to compare accuracy between regression models with different numbers of independent factors and RMSE and RMSE/SD to obtain a measure of precision, the latter being independent of the units in which the trait was measured, thus comparable across traits.

Traits were reanalysed, adjusting for variation in age at the time of slaughter instead of CCW. The differences in the response variable were minimal and therefore the results presented in this study are those corrected for CCW, or live weight in the case of CT traits.

Table 5.2 Means and standard deviations (SD) of video image analysis (VIA) dimensional measurements of lengths, widths and areas

Trait (unit)	Mean	SD
VIA lengths (cm)		
L1	75.14	3.19
L2	21.38	1.27
L3	14.66	1.70
L4	77.96	3.13
L5	91.60	3.57
Total length	96.19	3.57
VIA widths (cm)		
W1	19.46	1.23
W2	16.11	1.04
W3	22.09	1.36
W4	19.22	1.06
W5	23.32	0.80
W6	25.05	1.25
W7	12.74	0.74
W8	15.15	1.19
VIA areas (cm^2)		
A1	14919	1492
A2	16779	1678
A3	4607	461
A4	10906	1091
A5	15785	1578

5.3 Results and discussion

5.2.1 Prediction of computer tomography traits using a VIA system

Moderate accuracies were found in the estimation of CT traits using the VIA system. Coefficients of determination (R^2) ranged from 0.41 for lumbar length and LRMI to 0.72 for MLL-W and LRMV, respectively (Table 5.3). The precision measured by RMSE/SD ranged from 0.62 for MLL-A to 1.25 for lumbar length. A value above the unity for the RMSE/SD, as is the case for the lumbar length (1.25), indicates that the prediction model is as good an estimate as the raw average of the trait. However, for the majority of the traits, these results indicate that the VIA system provides a moderately accurate prediction of these CT traits; but only this one dataset was analysed, so far, so a validation analysis is required in the future to confirm the results found in the present study.

Table 5.3 Coefficients of determination (R^2) and root mean squared errors (RMSE) of the estimation of computer tomography (CT) measures using VIA carcass information.

Trait	R^2	RMSE	RMSE/SD
2D CT			
MLL-A	0.44	2.39	0.62
MLL-W	0.72	2.28	0.64
MLL-D	0.70	1.57	0.69
3D CT			
Lumbar Length	0.41	0.96	1.25
LRMV	0.72	54.23	0.66
LRMI	0.41	0.22	1.22

Moderate associations were found between VIA and CT measurements, which could be used to refine the VIA-based prediction models used in this study for the estimation of primal cuts and SMY (Table 5.4). The VIA standard prediction equations developed by E+V Technology and described in an earlier study (Rius-Vilarrasa *et al.* 2009b, Chapter 2) were used here to estimate the primal weights. The standard prediction models had moderate to high accuracies estimates (R^2 between 0.68 and 0.91) for LEG, CHUMP, LOIN, BREAST SHOULDER and SMY (Table 5.4). However, the VIA refined prediction equations increased the accuracy of the predictions by 8 to 38% and substantially increased the precision with which the VIA predicted the primal cuts by between 21 to 61 %, shown by a reduction in percentage of the RMSE between standard and refined VIA prediction models for all traits measured (Table 5.4). However, the percentage of improvement in the VIA prediction models including CT traits would probably have been smaller if the standard VIA prediction equations had been developed using the present dataset. Higher prediction accuracies for the estimation of primal meat yields than in the present study were found when the dataset of an earlier study was used to derive the VIA prediction equations (Rius-Vilarrasa *et al.* 2009b, Chapter 2). Nonetheless, the use of CT information (MLL-A, MLL-W, MLL-D, lumbar length, LRMV and LRMI) in the VIA prediction models was expected to improve the prediction models, especially on the loin area. A recent study in Norway by Kongsro *et al.* (2008) reported a more precise and reliable evaluation of weight and proportions of muscle, fat and bone tissue on the carcass using CT scanning compared to the evaluation using manual dissection. Therefore, using CT measurements as a reference method to refine VIA prediction models could also lead to improving the prediction of all primal joints in the carcass.

Table 5.4 Coefficients of determination (R^2) and root mean squared errors (RMSE) of the estimation of primal meat yields using both standard and refined VIA prediction models.

	VIA-standard		VIA-refined		Difference %	
VIA-primals	R^2	RMSE	R^2	RMSE	R^2 increase	RMSE increase
LEG	0.68	0.332	0.94	0.143	38.2	56.9
CHUMP	0.79	0.110	0.87	0.087	10.1	20.9
LOIN	0.78	0.230	0.90	0.158	15.4	31.3
BREAST	0.72	0.194	0.84	0.144	16.7	25.8
SHOULDER	0.83	0.311	0.90	0.236	8.4	24.1
SMY	0.91	0.696	0.98	0.270	7.7	61.2

The calibration of VIA against CT could potentially provide additional measures of carcass value online in abattoirs. The fairly high accuracy with which E+V Technology predicted MLL-W and LRMV (R^2 = 0.72 for both measurements), using VIA and the refined prediction equations, suggests that this automatic technology could be used to estimate certain muscularity (muscle shape) and muscling (muscle size) traits in carcasses on the slaughter line, which can currently only be measured non-destructively using CT, with relatively high cost and not online. The suggestion made by Hopkins (1996) to use VIA to quantify muscularity (muscle shape) seems to be supported by the present study. The refinements to the VIA predictions that have been made here, using CT measurements to calibrate VIA predictions, could also provide the means to distinguish the increase in loin muscling and muscularity of TM-QTL carriers at a commercial level, as reported in a later section of this paper.

5.2.2 TM-QTL effects on computer tomography traits estimated using a VIA system

The VIA-based predictions of CT measures showed that heterozygous carriers of the TM-QTL had a significantly larger MLL-D (+2.7%, $P < 0.05$) compared to the non-carriers (Table 5.5). Macfarlane *et al*. (2008), using the direct CT measure of MLL-D in live lambs in the same dataset, presented a higher difference (+6.7%, $P < 0.01$) between carriers and non-carriers of the TM-QTL. Direct CT measures of MLL-A, MLL-W and LRMV were also significantly associated with an increase in muscularity in the loin region of the TM-QTL carriers in the previous study (Macfarlane *et al.* 2008). However, in the current study, the VIA-based predictions of these traits were not found to be significantly different between carriers and non-carriers of the TM-QTL.

The detection of increased MLL muscularity or muscling in crossbred lambs carrying the TM-QTL by the VIA carcass evaluation system, is of fundamental importance to facilitate a payment system that will provide an economical incentive to increase muscling or muscularity through the use of the TM-QTL. The results in Table 5.5 suggest that the effect of the TM-QTL, expressed mainly as an increase in meat yield in the loin area as detected by dissection and CT (Macfarlane *et al.* 2008), could be partially quantified using the VIA estimates of CT measures in the loin region. Further experiments could allow a validation of these prediction models to estimate CT measurements using a VIA system. A validation analysis would test the robustness of the prediction models and hence the reliability of these estimates for their use in the evaluation of carcass quality.

Table 5.5 Least square means (LSMs) and standard error of difference (S.E.D) for TM-QTL carrier and non-carriers for computer tomography (CT) measurements.

Trait	LSMs		QTL effect			Factors†	
	Non-carrier	Carrier	S.E.D	*P*-value†	Carrier difference (%)	Sex	Weight§
2D CT							
MLL-A	22.83	22.74	0.69	NS	-0.4	*	***
MLL-W	72.44	72.78	0.69	NS	0.5	NS	*
MLL-D	29.96	30.78	0.33	*	2.7	**	***
3D CT							
Lumbar length	19.81	19.86	0.14	NS	0.3	NS	**
LRMV	665.8	677.7	9.25	NS	1.8	*	***
LRMI	2.97	2.93	0.03	NS	-1.4	NS	*

† NS = not significant; * P<0.05; ** P<0.01; *** P<0.001

§ Live weight fitted in the model as a covariate

5.2.3 TM-QTL effects on carcass classification scores and VIA characteristics

In terms of carcass classification scores, TM-QTL carrier animals had slightly better conformation and lower fat classes than non-carriers, although the effects were not significant (Table 5.6, P > 0.05). These results indicate that this recent scoring system would not allow any reward for the producers using the muscle growth enhancing effect of the TM-QTL in heterozygous crossbred lambs. In addition to standard and refined predictions of the primal weights, E+V Technology also provided some simple carcass measures (lengths, widths and areas) as illustrated in Figure 5.2. The effect of the TM-QTL on all of these traits was relatively small (-6.3 to +1.3 %) and mostly not significant, with the exception of one VIA measurement (W8) taken on the side of the carcass in the leg region, where carriers showed a shorter width (P < 0.05, -2.1%) than the non-carriers. Similar results were reported by Johnson *et al.* (2005), where another QTL affecting muscle growth (currently, known to be an allele of the myostatin gene), did not show any effect on length and width as direct linear measurements taken on the carcass after slaughter. In contrast, Marcq *et al*. (2002) reported evidence that a QTL associated with muscular hypertrophy (probably the same as that studied by Johnson *et al.* (2005) also resulted in an increase in carcass width. This finding was later confirmed in a study by Laville *et al.* (2004), where lambs homozygous for that QTL showed an increase in the width of the pelvis and shoulder.

Table 5.6 Least square means (LSMs) and standard error of difference (S.E.D) for TM-QTL carrier and non-carriers for MLC-CF scores of conformation and fat class and cold carcass weight (CCW) and VIA dimensional measurements (length, width and areas).

	LSMs		QTL effect			Factors[§]	
Trait	Non-carrier	Carrier	S.E.D	*P*-value[§]	Carrier difference (%)	Sex	CCW[¥]
MLC scores							
Conformation	2.97	3.06	0.08	NS	2.9	NS	***
Fatness	11.03	10.57	0.35	NS	-4.4	**	***
CCW	19.25	18.77	0.5	NS	-2.6	NS	-
VIA lengths							
L1	75.33	74.99	3.9	NS	-0.5	**	***
L2	21.65	21.21	2.37	NS	-2.1	NS	NS
L3	14.95	14.41	3.27	NS	-3.8	NS	NS
L4	78.29	77.61	4.39	NS	-0.8	**	***
L5	91.82	91.46	4.43	NS	-0.4	**	***
TL	96.61	95.87	4.47	NS	-0.8	**	***
VIA widths							
W1	19.44	19.5	1.87	NS	0.3	NS	***
W2	16.16	16.06	1.33	NS	-0.6	***	***
W3[†]	22.08	22.29	1.84	NS	0.9	NS	***
W4	0.170	0.160	1.57	NS	-6.3	NS	***
W5	23.31	23.35	1.05	NS	0.2	*	***
W6	25.07	25.12	1.53	NS	0.2	***	***
W7	12.67	12.81	0.97	NS	1.1	**	***
W8	15.31	15.00	1.55	*	-2.1	**	***
VIA areas							
A1	14939	14906	1035	NS	-0.2	*	***
A2	16842	16741	1107	NS	-0.6	*	***
A3	4603	4615	462	NS	0.3	*	***
A4	10911	10926	970	NS	0.1	**	***
A5	15832	15800	1339	NS	-0.2	**	***

[†] Rearing rank fitted in the model as fixed effect

[§] NS = not significant; * P<0.05; ** P<0.01; *** P<0.001

[¥] Cold carcass weight fitted in the model as a covariate

The effect of the TM-QTL on primal cuts, estimated using both standard and refined VIA prediction equations, was found to be non-significant for most of the traits (Table 5.7) - only predictions based on the standard VIA predictions are shown. Using the refined VIA prediction equations, the BREAST primal cut showed a lower primal weight (-3.8%, P < 0.01, results not shown in tables) associated with the effect of the TM-QTL. This result is in the same direction as the one reported by Macfarlane *et al.* (2008) where carriers of the TM-QTL showed smaller breast primal weights (-2.4%, P > 0.05), but the difference was not significant in this earlier study.

Table 5.7 Least square means (LSMs) and standard error of difference (S.E.D) for TM-QTL carrier and non-carriers for VIA primal cuts†.

	LSMs		QTL effect			Factors§	
Trait	Non-carrier	Carrier	S.E.D	*P*-value§	Carrier difference (%)	Sex	CCW¥
VIA predicted primal weights (kg)							
LEG	5.18	5.19	0.09	NS	0.2	NS	***
CHUMP	1.52	1.52	0.01	NS	0.0	NS	***
LOIN	3.47	3.45	0.02	NS	-0.6	***	***
BREAST	1.67	1.69	0.01	NS	1.2	NS	***
SHOULDER	6.65	6.64	0.03	NS	-0.2	**	***
SMY	19.66	19.65	0.08	NS	-0.1	**	***

† Estimations from the standard VIA prediction equations

§ NS = not significant; * P<0.05; ** P<0.01; *** P<0.001

¥ Cold carcass weight fitted in the model as a covariate

The results reported in the present study suggest that external examination (carcass classification scores), on which the current evaluation of carcass quality and the VIA system both rely, is limited in its ability to detect differences in muscling and muscularity of the MLL due to the effect of the TM-QTL in crossbred lamb heterozygous for the QTL. This situation could be different in homozygous carriers as the mode of inheritance of this QTL is not known yet. This limited ability is probably due to the fact that the TM-QTL effects are restricted to the loin area and are of relatively low magnitude (Macfarlane *et al.* 2008). The weight of the MLL directly measured by dissection was +7% higher in carriers compared to non-carriers of the TM-QTL (Macfarlane *et al.* 2008). However, the current study using VIA could not detect this difference and farmers would not be rewarded for the use of this QTL in heterozygous crossbred lambs in any VIA-based payment system. This leads to the following question: how large does the direct QTL effect on the dissected MLL-wt need to be so that VIA can detect significant differences in the LOIN primal cut, predicted by VIA? To answer this question, one must first determine what difference between carriers and non-carriers in the LOIN weight (based on VIA predictions) would be significant. A *post hoc* power calculation (Rasch *et al.* 1978) was used to find the magnitude of the TM-QTL effect required to be detected by the VIA system using the sample sizes available in the study, its standard deviation (0.36) and a probability of the error of first kind (5%) and of second kind (20%). Using this approach, it has been found that the required size of the TM-QTL effect on the LOIN weight (based on VIA predictions) is 0.18 kg. The estimated mean for non-carriers of this trait was 3.47 kg, as a result carriers would need to have a VIA-predicted LOIN weight of 3.65 kg, which is an increase of +5%. This value can easily be transformed into a MLL-wt value using a simple linear regression between both traits. The level of confidence (R^2) in this prediction equation was 65% (Figure 5.3).

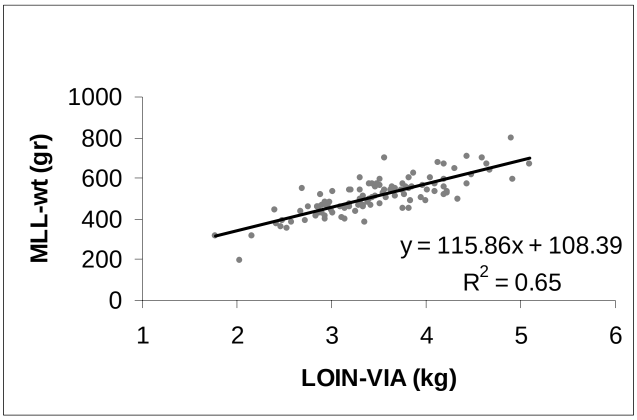

Figure 5.3 Linear correlation between MLL-wt and LOIN estimated by VIA (LOIN-VIA) with the prediction equation and the coefficient of determination (R^2).

Given the slope (b = 116) and the intercept (a = 108.4) of the prediction equation (*MLLwt = a + b x VIAloin*), the required direct effects in the MLL-wt to allow VIA to detect the difference in the VIA predicted LOIN weight is 40 g (+7.6%). This value is only slightly higher than the difference between carriers and non-carriers found in an earlier study (34g; Macfarlane *et al.* 2008), and may be seen in homozygous carriers of this QTL or in other genetic backgrounds or breeds.

5.2.4 TM-QTL effect on other carcass quality measurements

The TM-QTL did not significantly affect the VIA dimensional measurements (Table 5.6). However, the lambs carrying a single copy of the TM-QTL showed a significantly higher carcass compactness of 1.2% compared to the non-carriers (Table 5.8). The same trait calculated using dimensional carcass measurements was also found to be associated with the effect of another muscular hypertrophy QTL, as reported by Laville *et al.* (2004).

Table 5.8 Least square means (LSMs), standard error of difference (S.E.D) and TM-QTL effect for leg and carcass compactness and muscle and fat to bone ratios.

	LSMs		QTL effect			Factors†	
Carcass measurements	Non-carrier	Carrier	S.E.D	*P*-value†	Carrier difference (%)	Sex	CCW‡
Leg compactness	0.132	0.138	0.003	NS	4.4	NS	NS
Carcass compactness	0.241	0.244	0.001	**	1.2	NS	NS
Muscle:bone ratio	2.204	2.152	0.031	NS	-2.4	***	NS
Fat:bone ratio	5.081	5.465	0.378	NS	7.0	**	NS
Loin dissection (MLL-Wt)	500.64	514	6.329	*	2.6	NS	***

† NS = not significant; * P<0.05; ** P<0.01; *** P<0.001

‡ Cold carcass weight fitted in the model as a covariate

Other carcass measurements, such as leg compactness, muscle to bone ratio and fat to bone ratio were not found to be significantly different between carriers and non-carriers of the TM-QTL (Table 5.8). Holloway *et al.* (1994) reported a strong correlation between muscularity and muscle to bone ratio. Carriers of the TM-QTL had greater MLL volume, depth, width and area using CT measurements (Macfarlane *et al.* 2008). However, muscle to bone ratio measured using VIA did not show a significant increase. The corresponding total bone weight in the carcass was heavier using CT for the carriers compared to the non-carriers (Macfarlane *et al.* 2008), and consequently similar muscle to bone ratios were found for both carrier and non-carriers of the TM-QTL. Inconsistencies in the relationship between muscularity and muscle to bone ratio, where bones were shown to be proportionally longer or heavier, have been reported in earlier studies (Purchas *et al.* 1992; Hopkins and Roberts (1995).

Carcass compactness has been reported to be correlated with subjective conformation score, perimeter of the leg and width of the leg, and strongly correlated with cold carcass weight (Díaz *et al.* 2004; Albertí *et al.* 2005; Indurain *et al.* 2008). The appearance of 'blockiness' of the whole carcass has been shown to have a positive influence on conformation score (Indurain *et al.* 2008). The use of this index as a measure of carcass value could be made possible with the introduction of VIA systems in the UK lamb abattoirs. However, further research is needed to investigate the associations between increased carcass compactness and carcass value, meat quality and animal welfare traits.

5.2.5 Prediction of meat quality traits using a VIA system

Variances of tenderness, as measured using the MIRINZ tenderometer (ToughB) and Volodkevitch-type tenderometer (ToughA), were poorly explained by models using VIA measurements (1 to 6 %) in the leg for the two methods respectively (Table 5.9). A higher proportion of variance was explained in the model for IMF in the loin (18%) or leg (21%). These low associations between VIA and MQ traits were in the range of expected values since MQ characteristics are very difficult to measure at a carcass level.

Table 5.9 Adjusted coefficient of determination (Adj-R^2), root mean squared error (RMSE) for prediction of meat quality traits using VIA information.

Trait	Adj-R^2	RMSE	RMSE/SD	SEX	CCW[†‡]	VIA predictors[§]
ToughA						
LOIN	0.16	1.27	0.93	NS	*	W3 & W10
LEG	0.06	0.73	0.99	NS	**	L5
ToughB						
LOIN	0.11	1.28	0.96	NS	**	W3
LEG	0.01	0.60	1.00	NS	NS	No significant factors
IMF						
LOIN	0.18	0.70	0.93	NS	**	W1, W2 & W3
LEG	0.21	0.57	0.90	NS	**	L9, TL & W10

[†] Weight fitted in the model as a covariate

[‡] NS = not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

[§] Factors included in the model $p<0.05$

Methods for the evaluation of MQ characteristics are being increasingly investigated with the aim of improving the effectiveness of the lamb industry at producing a consistent, high quality product. Computer tomography, which is currently being used in sheep breeding programmes for the evaluation of carcass quality, could also provide the means to select on MQ traits. In two different studies (Karamichou *et al.* 2006; Navajas *et al.* 2006), live CT measurements have been reported to predict MQ traits with moderate accuracy, most likely due to the associations between intramuscular fat and CT-measured muscle density. Karamichou *et al.* (2006) reported significant phenotypic and genetic correlations between CT and meat eating quality traits, and Navajas *et al.* (2006) also found strong associations between CT muscle density and intramuscular fat. While CT scanning could help in the selection for MQ traits in breeding stock, direct measurements of these traits in slaughter lambs are still of prime interest, as processing operations (i.e. electrical stimulation) might influence in the final quality of the product. A recent study by Lambe *et al.* (2008b) reported an increase in the accuracy of prediction of IMF in the loin using a combination of VIA in live lambs together with CT measures. However, similar to the results presented here, that study found that little variation in tenderness (shear force) could be explained by live VIA traits. On the contrary, Kröger *et al.* (2006), using dual energy X-ray absorptiometry (DEXA), reported a moderate accuracy in the estimation of tenderness of steaks (R^2 = 0.69). Near infrared reflectance spectroscopy (NIR) has also been used with some success to predict MQ traits in lamb meat samples (Andrés *et al.* 2007) and has a potential to be used in a non-invasive manner, so might be more suitable for future online use in an abattoir.

The present study showed that VIA measurements are poor predictors of these two MQ traits: tenderness and IMF. However, additional information and/or technologies could increase the capabilities of the VIA system in the estimation of MQ characteristics. Additional benefits might arise from improving the VIA system further through calibration against CT measures associated with MQ traits, which still remains to be investigated. To date, genetic selection for MQ characteristics has shown slow progress. This is mainly due to the lack of economic incentives at a commercial level and a lack of suitable online methods for measuring MQ. However, the increasing research into objective technologies to estimate some MQ traits could provide the means to reward the producer for these traits and therefore increase their motivation to improve product quality. In addition, the upcoming information on molecular genetic predictors of MQ traits could also soon be applied in sheep breeding programmes by MAS (Gao *et al.* 2007), helping to increase the genetic progress made on these traits.

5.4 Implications

This study has investigated the effects of the TM-QTL on various carcass characteristics of heterozygous crossbred lambs measured by subjective carcass classification and a VIA system. The potential of the VIA system in the estimation of CT muscularity measurements of the loin region and MQ was also evaluated. It has been demonstrated earlier (Macfarlane *et al.* 2008) that one copy of the TM-QTL has biologically and statistically significant effects on the MLL muscle. However, in practice, the carcass evaluation system, used currently in the industry for carcass conformation and fat class would not be able to identify an effect of this relatively small magnitude, and so would not reward for the total increase in MLL muscularity gained through the use of the TM-QTL in breeding programmes. The VIA system was shown to have moderate potential in the prediction of loin muscle traits measured by CT, especially for loin muscle volume. This suggests that VIA estimates of CT traits could have the potential to detect differences in loin muscle traits between carcasses from carriers and non-carriers of the TM-QTL in the abattoir. Additionally, other carcass quality measures calculated using VIA information, such as carcass compactness, could provide the means to reward producers for the use of a QTL enhancing product quality, if the associations between carcass compactness and carcass value are positive. Furthermore, the fine-mapping of QTL affecting growth and carcass composition would allow more precise genotyping, and, therefore, provide more reliable identification of TM-QTL carriers and non-carriers as well as increase the statistical power of the analyses to evaluate the effects of this QTL.

In summary, the subjective evaluation of carcass conformation has only a limited potential to identify increased muscling due to the effect of one copy of the TM-QTL. VIA was shown to have increased capabilities in the estimation of MLL muscling through calibration against CT measures. Additionally, carcass compactness calculated using VIA information has been shown to be associated with the effect of the TM-QTL. Further analysis will help to validate the associations between VIA and CT carcass traits and provide more information on the value of the TM-QTL for the UK sheep industry.

Chapter 6

General discussion

6.1 Introduction

This thesis was carried out in the framework of an industry project led by the Meat and Livestock Commission (MLC) and jointly funded by the English Beef and Lamb Executive (EBLEX), Hybu Cig Cymru (HCC), Quality Meat Scotland (QMS), the Livestock and Meat Commission for Northern Ireland (LMCNI) and the LINK project LK0670 (Sustainable Livestock Production program) (Industry Report 2007). The project was set up in Welsh Country Foods, a large abattoir in North Wales (Gaerwen) and aimed at assessing the potential of the VSS2000 VIA equipment from E+V Technology GmbH to evaluate carcass quality. Two groups of carcass traits were considered. The first group included conformation and fat class scores and the second group included meat yield. In the industry project the ability of the VSS2000 to estimate conformation and fat class scores was evaluated. In Chapter 2 of this thesis, the potential of the VSS2000 to predict meat yields was investigated.

Video image analysis based systems used to estimate carcass value from livestock species have been reported by several authors (Horgan *et al.* 1995; Steiner *et al.* 2003b; Hopkins *et al.* 2004), but this project tested for the first time a VIA system under UK abattoir conditions. The findings in Chapter 2 provide evidence of the potential of this technology to be used in a value based marketing system (VBMS) in the lamb industry of the UK and in sheep breeding programmes to improve carcass quality. Therefore the objectives of Chapters 3 and 4 were to investigate the genetic parameters of VIA carcass measurements and the associations between these and both current carcass quality traits such as conformation and fat class and performance traits in crossbred lambs. In Chapter 5, the VIA system was tested for its ability to detect differences in carcass quality characteristics in slaughter lambs carrying a mutation at the quantitative trait locus (QTL) for increased loin muscularity, and hence to investigate the potential economic benefit of this QTL in such a VIA-based VBMS.

6.2 Evaluation of a VIA system under UK abattoir conditions

The industry project was set up to investigate the potential of VIA equipment to be used as a lamb carcass grading system in the UK and included three main objectives. One objective was to investigate the potential of the VIA system to predict meat yield (Chapter 2) and will be reviewed in the next section. The other two objectives were to develop an accurate generic prediction equation for conformation and fat class and to ensure compatibility between the current subjective classification system and the VIA system. A brief review of the findings from these two last objectives, which have not been analysed within this thesis, will be presented in the next paragraph, as it highlights important features of this technology, including its use in predicting meat yield rather than conformation and fat class scores. Then, the sections of this chapter will review the most significant findings of this thesis and discuss their relevance to the UK lamb industry.

Most abattoirs in European countries use subjective scores for conformation and fatness to sort and value carcasses for the market (CEC 2002). Therefore, it was a requirement that any automatic technology with the potential to be installed in UK lamb abattoirs could provide such carcass measurements. The trial, set up in 2005, consisted of a comparison between a panel of three UK expert MLC classifiers, in addition to the in-plant MLC classifier, and the VIA system in the assessment of carcass conformation and fat class. The results, presented in the industry report which is available online (UK devolved levy bodies 2007), indicated that the VIA system was more accurate and consistent than MLC experts in the estimation of carcass conformation, but slightly less accurate and consistent in the prediction of fat class, compared to the in-plant MLC classifier.

6.3 VIA to predict meat yield

Meat producing countries have shown increasing interest in shifting from subjective to objective carcass grading systems with the aim of increasing accuracy and reliability in the evaluation of carcass quality (Horgan *et al.* 1995; Steiner *et al.* 2003b; Hopkins *et al.* 2004). In Chapter 2, the use of the objective VIA system from E+V Technology (VSS2000) in comparison with the current subjective carcass classification for conformation and fatness system (MLC-CF) to predict various primal meat yields (LEG, CHUMP, LOIN, BREAST and SHOULDER). The use was presented and the benefits of moving towards a more consistent system to determine carcass value in abattoirs were highlighted. Results in Chapter 2 indicated that use of the VIA system to estimate meat yield of different primal joints in lamb carcasses was more accurate and precise than the MLC-CF carcass classification scheme. The use of this VIA system also shows an increase in accuracy (average = 6%) and precision (average = 31%) compared to using only CCW in the prediction model to estimate weights of primal joints as it is shown in Table 6.1 below.

Table 6.1 Coefficient of determination (R^2) and root mean squared error (RMSE) for the prediction of carcass primal joints (n = 443, Chapter 2) using cold carcass weight (CCW), MLC conformation and fat scores and VIA along with CCW.

	CCW		MLC & CCW		VIA & CCW	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
LEG	0.84	0.335	0.94	0.213	0.97	0.155
CHUMP	0.89	0.058	0.92	0.048	0.94	0.042
LOIN	0.86	0.323	0.89	0.206	0.89	0.204
BREAST	0.78	0.192	0.82	0.176	0.86	0.156
SHOULDER	0.94	0.252	0.95	0.233	0.96	0.222
TOTALS	0.98	0.398	0.99	0.292	0.99	0.254

Differences in accuracy and precision were also found between using CCW and MLC + CCW. The increase in accuracy and precision for all the primal joints was lower compared to using VIA, but still significant with an average increase in accuracy of 4% and 8% in precision. Additionally, the VIA system improved consistency predicting primal joint weights and was less influenced by environmental effects such as carcass sex and slaughter day than was the MLC-CF scheme as reported in Chapter 2. These findings indicate that the VIA system used in the present study could provide higher accuracy, precision and consistency in estimation of carcass meat yield online in abattoirs than the current MLC-CF scores (conformation and fatness). These findings corroborate other British, Australian and American studies (Horgan *et al.* 1995; Stanford *et al.* 1998; Brady *et al.* 2003) where different VIA systems showed higher accuracy and precision in predicting total primals in comparison with other more subjective techniques.

6.4 The use of VIA carcass measurements in sheep breeding programmes

Breeding strategies in place in the UK focus on selection in purebred terminal sire breeds based on the Lean Growth Index score to improve the carcass quality of crossbred slaughter lambs (Simm and Dingwall 1989). This index was created in response to consumer's demand for leaner meat and the need to increase productivity in terms of increased lean meat yield with faster finishing times. Using this index to select superior terminal sires helps increase lean meat yield in the carcass, whilst limiting any associated rise in fatness. Weight data and ultrasonic measurements of muscle and fat depth are used to predict total carcass muscle and fat. Relative economic weightings of +3 and –1 are then applied to produce an overall index on which rams can be ranked. The use of this index over the last 15 years has provided crossbred lambs with heavier carcasses that yield more saleable lean meat and generate substantially higher market returns. However, work by Wei and van der Werf (1994) suggested that higher genetic responses in crossbred progeny could be achieved if breeding goals were defined at the crossbred level and if information from these animals was used in the evaluation of purebred sires. Jones *et al.* (1999) reported that fat scores taken on crossbred lambs could be valuable in purebred selection programmes. The wider uptake and use of most efficient breeding technologies would allow the UK sheep industry to increase its competitive edge in meeting domestic and European-wide market demands for quality lean lamb. Therefore, Chapters 3 and 4 investigate the potential of a VIA system on crossbred lambs for its use in the UK genetic breeding programmes.

One of the most significant benefits of using VIA systems to predict carcass value in abattoirs lies in its potential use as a breeding tool. The VIA system has proven to be an accurate, precise and consistent method to estimate weights of various primal joints (Chapter 2). Therefore, VIA carcass information could provide a very valuable source of information which could be used in selection programmes to improve carcass quality. Such use requires knowledge of the genetic parameters of those VIA based traits. Estimates of genetic parameters for VIA carcass measurements (primal meat yields and carcass dimensional measurements) were investigated in Chapters 3 and 4. Heritabilities for weights of primal joints (leg, chump loin, breast and shoulder) estimated using VIA ranged from 0.07 to 0.26 for chump and loin respectively, and suggested that, for most of the primal joints, there was sufficient genetic variability for genetic progress on these traits. However, strong genetic correlations (> 0.63) between the primal joints indicated that it would be difficult to select for increased weight of one of the primals without increasing the weight of the remaining of the primals as a correlated response. The genetic variability of primal joint weights predicted from MLC-CF scores (conformation and fat) was also investigated (Chapter 4). Heritabilities were lower than those estimates for VIA primal joints reported in Chapter 3, and ranged from 0.05 for the loin to 0.17 for the leg. These results indicated that a higher genetic response for increasing weight of the primal joints could be achieved by using VIA information in the selection programmes to improve carcass quality compared to using measures of primal joint weights estimated using MLC-CF scores. Additionally, in Chapter 3, the repeatability as a reliability measure of this technology was investigated.

Consistency in the evaluation of carcass value is crucial to increase consumer confidence in lamb products, but also to help producers improve carcass quality. The high repeatability estimates for weight of primal joints reported in Chapter 3 indicated that VIA technology could provide a robust measure of carcass quality in abattoirs. The VIA system showed low residual variances which contributed to the very high repeatabilities for predicted primal weights, leg, chump, loin, breast and shoulder (average 0.96) (Chapter 3). Repeatability estimates for VIA traits were obtained off the main slaughter line with a consistent methodology (scanned by the same person). Somewhat lower repeatability estimates might occur for a fully automated VIA scanning (installed online in abattoirs). Lamb carcasses integrated in the slaughter line will be VIA scanned without any individual assistance. Some swing of the carcass while the images are being taken could be expected and that could influence the consistency with which carcasses are scanned.

Genetic parameters for performance traits have been reported in previous studies, however, to the best of my knowledge, this is the first time that estimates of genetic correlations between VIA traits and performance traits have been investigated. Results in Chapter 3 showed moderate to high heritability estimates (0.25 – 0.55) for average daily gain (ADG), scanning live weight (SW), ultrasonic measures of muscle (UMD) and fat (UFD) depths (performance traits) and cold carcass weight (CCW). The correlations found between VIA traits and performance traits in a crossbred population were favourable (Chapter 3) and suggested that a combination of these traits in a breeding programme could provide an overall positive response to selection. These findings provide encouraging information for breeders willing to improve carcass quality based on information from meat yields as predicted using VIA. However, incorporation of VIA traits (on crossbred lambs) into the current selection programmes, which at present include carcass measures only on purebred rams, needs to be investigated in order to optimise the selection to achieve the maximum genetic gain in the breeding goal traits. In particular, it would be interesting to explore the additional genetic gain achieved by combining purebred and crossbred information in the selection programmes, compared to using only purebred information. The additional genetic gain from using crossbred information would then need to be justified against the extra economic cost derived from the recording and analysis of these data in the current commercial practices.

Although there are limitations in improving carcass conformation by genetic selection due to its positive genetic correlation with fatness in a wide range of breeds (Lewis *et al.* 1996; Conington *et al.* 1998; Jones *et al.* 1999; Moreno *et al.* 2001; Bibe *et al.* 2002; Karamichou *et al.* 2006), sheep breeders are still interested in the improvement of this trait, mainly because of its current substantial economic impact.

Linear body measures have been suggested as an objective measure of body conformation in sheep (Waldron *et al.* 1992; Bibe *et al.* 2002) and they could be used in breeding programmes as indirect selection criteria to improve carcass conformation. In Chapter 4, the genetic parameters of carcass dimensional measurements (lengths, widths and areas) obtained using VIA were investigated along with the associations between these traits and conformation and fatness. Moderate to high genetic and phenotypic correlations between carcass shape (conformation) and VIA linear carcass measurements were found, which could provide the means to improve conformation by genetic selection. While selection for shorter carcasses as measured in Chapter 4 could improve carcass conformation, this should be investigated carefully. There is a possibility that selection for shorter carcass lengths could lead to smaller overall carcass size with lower cold carcass weight, hence resulting in an economic loss for the producer as payments are based mainly on carcass weight. Likewise, there was a trend in the genetic correlations between conformation and carcass widths indicating that conformation could also be improved by selecting for wider carcasses as measured by VIA.

Improvement of carcass conformation by altering the carcass shape could be due to changes in weight of the muscle relative to a skeletal dimension (lengths of the bones), defined as muscularity by Purchas *et al.* (1991). Favourable phenotypic and genetic associations between muscularity and shape of the carcass or primals in sheep have been reported in the literature (Laville *et al.* 2004; Wolf and Jones 2007; Navajas *et al.* 2007). Since muscularity is independent of fatness (Navajas *et al.* 2007), using VIA-DM in a selection programme could potentially provide the means to improve carcass conformation while limiting the increase in overall fatness. However, results in Chapter 4 could not confirm this due to high standard errors which made elucidating the genetic associations between the VIA-DM and fat class scores difficult.

The enhancement of conformation and muscularity may improve the shape of the retail cut as well (i.e. plump joints and rounder chops), which has an effect on the attractiveness of the meat to consumers, and hence may improve demand for and consumption of lamb (Jeremiah *et al.* 1993; Laville *et al.* 2004). The use of VIA-DM as a selection criterion to improve conformation was investigated in Chapter 4. Moderate to high heritability estimates (0.20 – 0.53) were found for linear and area carcass traits measured by VIA. The genetic correlations for VIA-DM in Chapter 4 suggested that it would be difficult to select for larger hind legs (longer and wider) without a correlated increase in the length of the whole carcass. The selection of carcasses with larger hind legs would also lead to carcasses with wider chest and shoulders. The expected response to selection on carcass shape (i.e. larger hind legs) based on several carcass dimensional measurements also depends on other genetic parameters (i.e. heritability). The development of a selection index where all component characters are combined is required to determine the effect of selection based on VIA-DM to increase the conformation grade.

6.5 The effects of the TM-QTL on VIA characteristics

In the UK, a QTL in OAR 18, which has been referred to in Chapter 5 as TM-QTL (= Texel muscling-QTL), has been shown to increase eye muscle depth by 4 to 8% in Texel sheep (Walling *et al.* 2004; Matika *et al.* 2006). In a recent study, crossbred lambs carrying a single copy of the TM-QTL had a higher *m. longissimus lumborum* depth (MLL-D), width (MLL-W) and cross-sectional area (MLL-A) by 6.7%, 3.0% and 5.1%, respectively as measured by *in vivo* CT, and higher dissected weight of this muscle by 7.1%, compared to their non-carrier contemporaries (Macfarlane *et al.* 2008). The effects of this QTL on different carcass traits already evaluated using MLC scores, at a commercial level and with the potential to be evaluated using the VIA system, were investigated in Chapter 5.

The use of molecular genetic techniques to improve carcass quality might imply an extra economic cost for the producers who take up this technology. In order to successfully include molecular genetic findings in the sheep industry, the producer needs to be rewarded for any increase in carcass value achieved by the use of molecular techniques. Results reported in Chapter 5 suggested that, while subjective

MLC scores (conformation and fat) to assess carcass value still remain the carcass grading system in the UK, producers willing to use TM-QTL to help improve carcass quality in their slaughter lambs will not be economically rewarded for the increase in muscling or muscularity associated with the QTL effect. Additionally, carcass shape measured as individual lengths, widths and areas by VIA were not significantly influenced by the TM-QTL, indicating that even if a more sophisticated grading scheme was implemented that utilised VIA, producers would still not be rewarded for the use of TM-QTL.

Other carcass quality measures such as carcass compactness (hind leg width / total carcass length), leg compactness (sum of back and side hind leg widths / total carcass length), muscle to bone ratio (muscle weight / bone weight of whole carcass) and fat to bone ratio (fat weight / bone weight of whole carcass) calculated using VIA information were investigated in Chapter 5 to determine whether muscling or muscularity differences between carriers and non-carriers of the TM-QTL could be detected using a more specific range of traits. The results suggested that producers willing to use the TM-QTL to enhance product quality could be economically rewarded if the measure of carcass compactness was introduced as a measure of carcass quality in abattoirs. Carcass compactness has been reported to be correlated with subjective conformation score, perimeter of the leg and width of the leg, and strongly correlated with cold carcass weight (Díaz *et al.* 2004; Albertí *et al.* 2005; Indurain *et al.* 2008). The appearance of 'blockiness' of the whole carcass has been shown to have a positive influence on conformation scores (Indurain *et al.* 2008). The potential introduction of VIA systems in UK lamb abattoirs could encourage the use of this index as a measure of carcass value, and hence provide the means to reward producers for any increase in carcass quality due to the TM-QTL effect. However, further research is needed to investigate the associations between increased carcass compactness and carcass value, meat quality and animal welfare traits.

Standard VIA prediction models (as used in Chapters 2, 3 and 4), developed by E+V Technology using data from dissection of primal joints as a reference for the prediction of primal joint weights, showed a modest ability to detect carcasses with increased loin muscularity due to the TM-QTL effect. The possibility of refining the standard VIA prediction models using CT measurements on the loin and leg muscles available from the same lambs (as described by Macfarlane *et al.* 2008) provided increased capabilities for the VIA system in the detection of the TM-QTL effects. The new refined prediction models, developed by E+V and evaluated in Chapter 5, increased the accuracy of prediction of all primal cuts by 16% on average compared to the previously derived standard VIA prediction equations. However, despite the increase in accuracy in prediction of primal meat yields, the significant differences in muscling of the loin or muscularity between carriers and non-carriers of the TM-QTL found by Macfarlane *et al*. (2008) still could not be detected by these refined VIA predictions of primal meat yield.

From the refinement of the VIA system against CT measurements, new VIA prediction models were obtained, which also provided estimates of *m. longissimus lumborum* width, depth and cross-sectional area (MLL-W, MLL-D, MLL-A respectively), leg muscularity index and muscle volume as measured by CT (Chapter 5). The VIA-based predictions of CT measures showed that heterozygous carriers of the TM-QTL had a significantly larger MLL-D (+2.7%, $P < 0.05$) compared to the non-carriers. Work by Macfarlane *et al.* (2008), using the direct CT measure of MLL-D in live lambs in the same dataset, reported a higher difference (+6.7%, $P < 0.01$) between carriers and non-carriers of the TM-QTL. The results in Chapter 5 also suggested that the effect of the TM-QTL, expressed mainly as an increase in meat yield in the loin area as detected by dissection and CT (Macfarlane *et al.* 2008), could be partially quantified using the VIA estimates of CT measures in the loin region. However, validation work is required where the new VIA prediction models to estimate CT traits are tested in a new dataset.

The use of VIA on lamb carcasses may also offer the possibility to estimate MQ traits in a non-destructive and cost-efficient way. Work by Lambe *et al.* (2008b) suggested that the use of VIA information of live lambs could help in prediction of MQ by predicting intra-muscular fat (IMF). In Chapter 5, variances of tenderness, as measured using the MIRINZ tenderometer (ToughB) and Volodkevitch-type tenderometer (ToughA) were poorly explained by models using VIA measurements (1 to 6%) in the leg muscle for the two methods respectively. A higher proportion of variance was explained in the model for IMF in the loin (18%) or leg (21%) muscles. These low associations between VIA and MQ traits were in the range of expected values from the literature (Lambe *et al.* 2008a) since MQ characteristics are very difficult to measure at a carcass level.

Work by Kröger *et al.* (2006), on lamb using dual energy X-ray absorptiometry (DEXA), reported a moderate accuracy in the estimation of tenderness of steaks (R^2 = 0.69). Near infrared reflectance spectroscopy (NIR) has also been used with some success to predict MQ traits in lamb meat samples (Andrés *et al.* 2007) and has the potential to be used in a non-invasive manner, so it might be suitable for future online use in an abattoir. The present study showed that current VIA measurements are poor predictors of these two MQ traits: tenderness and IMF. However, additional information and/or technologies, as mentioned above, could increase the capability of the VIA system predicting MQ characteristics.

6.6 Conclusions

In this thesis, the evaluation of a VIA system under UK lamb abattoir conditions indicates that this technology provides a fast, non-invasive, accurate, precise and consistent method to predict weights of primal joints: leg, chump, loin, breast and shoulder. This technology, installed online in the abattoir, could provide accurate information from crossbred lambs, which could then be used in purebred selection programmes to enhance carcass quality by improving carcass conformation or primal meat yield of the joints while limiting the increase in fatness. High accuracies, based on repeatability estimates, in the prediction of meat yield using the VIA system indicates the potential of this VIA information for use in genetic programmes. However, further work is required to investigate the genetic gain and response to selection when using combined crossbred and purebred information in breeding programmes.

In addition, genetic traceability to link individual information of slaughter lambs with its sire and dam is needed if this VIA information is to be used in breeding programmes. This will require the set up of an automated identification system for the traceability on the current production line speed. Electronic ID systems for sheep are going to be compulsory for the European Union by 2010 mainly to ensure the traceability of each animal to fight animal diseases more effectively but will also be of great value to set up recording system to feedback information for breeding programmes.

VIA was shown to have increased capabilities in the estimation of muscling and muscularity in the loin through calibration against CT measures. Further analysis would help to validate the associations between VIA and CT carcass traits and provide more information of the value of the TM-QTL for the UK sheep industry. The implementation of automatic technologies such as VIA can offer a significant opportunity to record very accurate information on carcass characteristics which could provide an opportunity for producers to capture greater economic rewards for using improved genetics by receiving a premium price for superior lambs that yields a superior carcass.

6.7 Future research

Although the estimates of genetic parameters provided allowed some insight into the genetic control of the traits of interest and the direction and general magnitude of their relationships with other important traits, larger datasets are likely to provide clearer associations by reducing the magnitude of the standard errors found in the present study. Genetic relationships with all other relevant traits including those important in maternal and terminal sire breeds will need to be investigated to check for undesirable side effects of selection for improved carcass quality. Of special interest are the relationship between the maternal traits which are currently under selection in the breeding objectives for hill or upland breeds with carcass traits measured using the VIA system. These would need to be understood before these traits can be combined in any selection index. The improvement of carcass shape (conformation) or weight of primal meat yields may be associated with an increase in lambing difficulties. This should be evaluated in terms of their consequences on production and animal welfare as well as their economic impact.

Economic incentives placed on meat yield and increased capabilities of the VIA system could encourage the UK lamb industry to wide uptake of this technology. Video image analysis systems combined with other *post mortem* measurements and with technology that can objectively measure meat quality traits (i.e. NIR) could provide a more comprehensive evaluation of product quality. The calibration of the VIA system to predict MQ characteristics might be a potential area of research in the near future with high relevance for the sheep industry. This information collected from slaughter lambs could be feed back to the producers and breeders to help in the selection of breeding stock for improved carcass and meat quality characteristics.

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